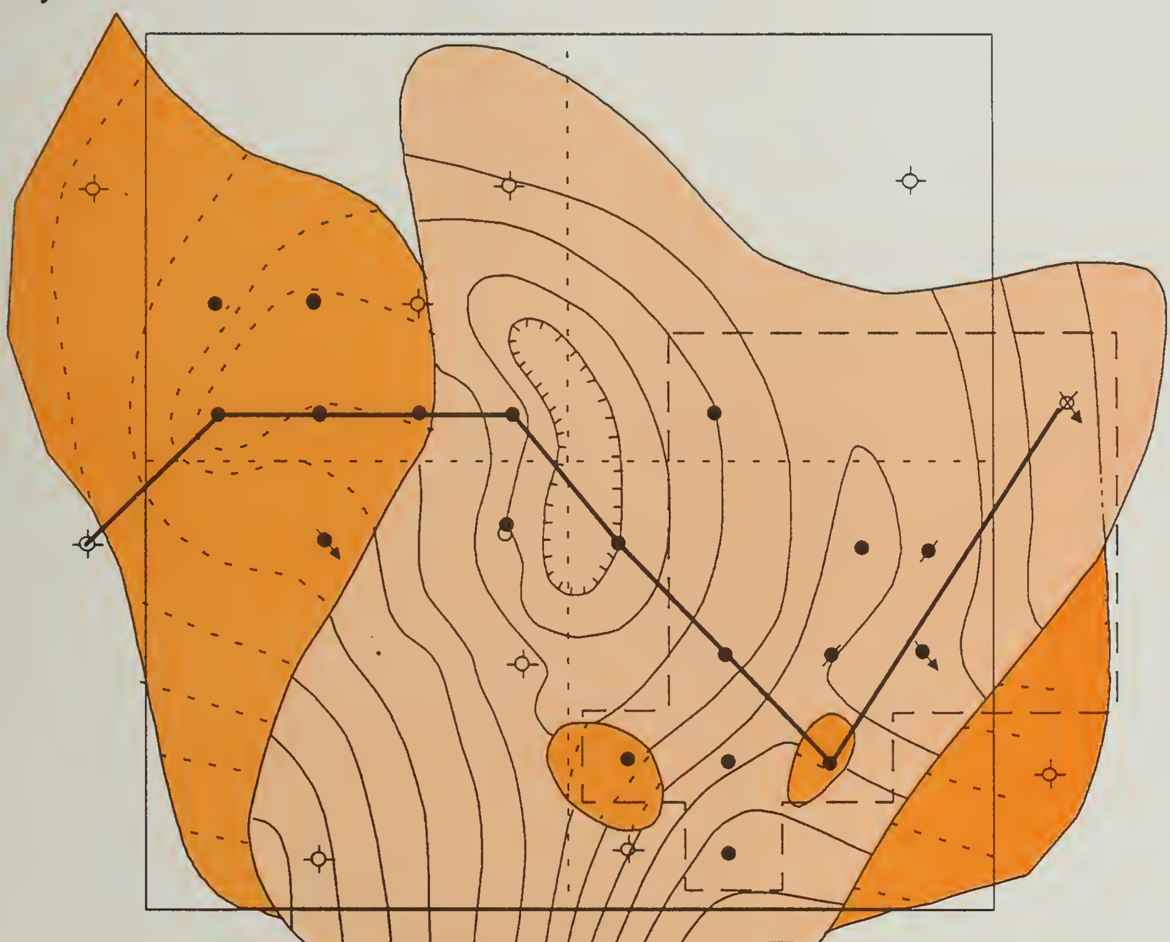
Geol Survey

Analysis of the Aux Vases (Mississippian) Petroleum Reservoirs of Energy Field, Williamson County, Illinois

Bryan G. Huff



ILLINOIS STATE GEOLOGICAL SURVEY
Department of Energy and Natural Resources

Illinois Petroleum 141
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ABSTRACT

Energy Field in Williamson County, Illinois, was discovered in 1968. Oil production is from the sandstone bar facies of the Aux Vases Formation (Valmeyeran) at a depth of about 2,400 feet. The trapping mechanism is stratigraphic; however, oil-to-water production ratios are affected by structural position. Twenty-three oil wells, 17 dry holes, and one injection well have been drilled in the field area. The field is under development.

The economically important siliciclastic zone ranges from 6 to 35 feet thick and consists primarily of sandstones and shales. Two sets of distinct, sandstone bar complexes developed within this zone: one in the northern portion of the study area and one in the southern portion. Both bar complexes have lower and upper reservoirs that are up to 24 and 10 feet thick, respectively. The reservoir facies consists of fine and very fine grained sandstones cemented by clay, quartz overgrowths, and calcite. The sandstones may pinch out between wells, a distance of 660 feet, and grade laterally and vertically into encapsulating shales, calcareous shales, and calcareous sandstones. The upper sandstones also grade into limestone.

The lower sandstones are marine tidal ridges or bars, apparently deposited during a marine regression, as interpreted from the evidence of multiple occurrence, morphology, petrography, and sedimentary structures visible in core. The upper sandstones are winnowed, crestal sandstone bars deposited during a marine transgression. These interpretations are based on repeated areal association of upper and lower bars, ichnofauna, associated shallow facies, and differences in petrology of the bars. The mechanism facilitating formation of the upper bars is believed to be accumulation of sediments on topographically high areas over the lower sandstones. Winnowing of these sediments by wave action produced the porosity and permeability. Over most of the field, the lower and upper sandstones are separated by a thin, impermeable interval of algal-bound, calcareous sandstones, shales, and biocalcarenitic quartzose sandstones interpreted, on the basis of features observed in core and areal distribution, to be intertidal mud flat deposits. The lower sandstone ridges occur at an apparently predictable interval of 3/4 mile, a characteristic that may prove useful in exploration for similar reservoirs.

The primary drive mechanism at Energy Field is solution gas. The oil–water contact is –1,923 feet (subsea) in the southern bar complex and –1,974 feet (subsea) in the northern bar complex. These contacts occur in the lower sandstones; a separate oil–water contact in the upper sandstones has not been observed. The different oil–water contacts and initial pressure data show that the northern and southern complexes are not in communication.

The original oil in place (OOIP) is calculated to be 4,004,000 barrels of oil (BO). A recovery efficiency of 20.9% of OOIP was calculated for the field; primary and secondary methods are projected to be 7.3% and 13.6%, respectively. Remaining mobile oil in place, recoverable through primary and selective secondary recovery efforts, is estimated at a minimum of 531,000 BO.

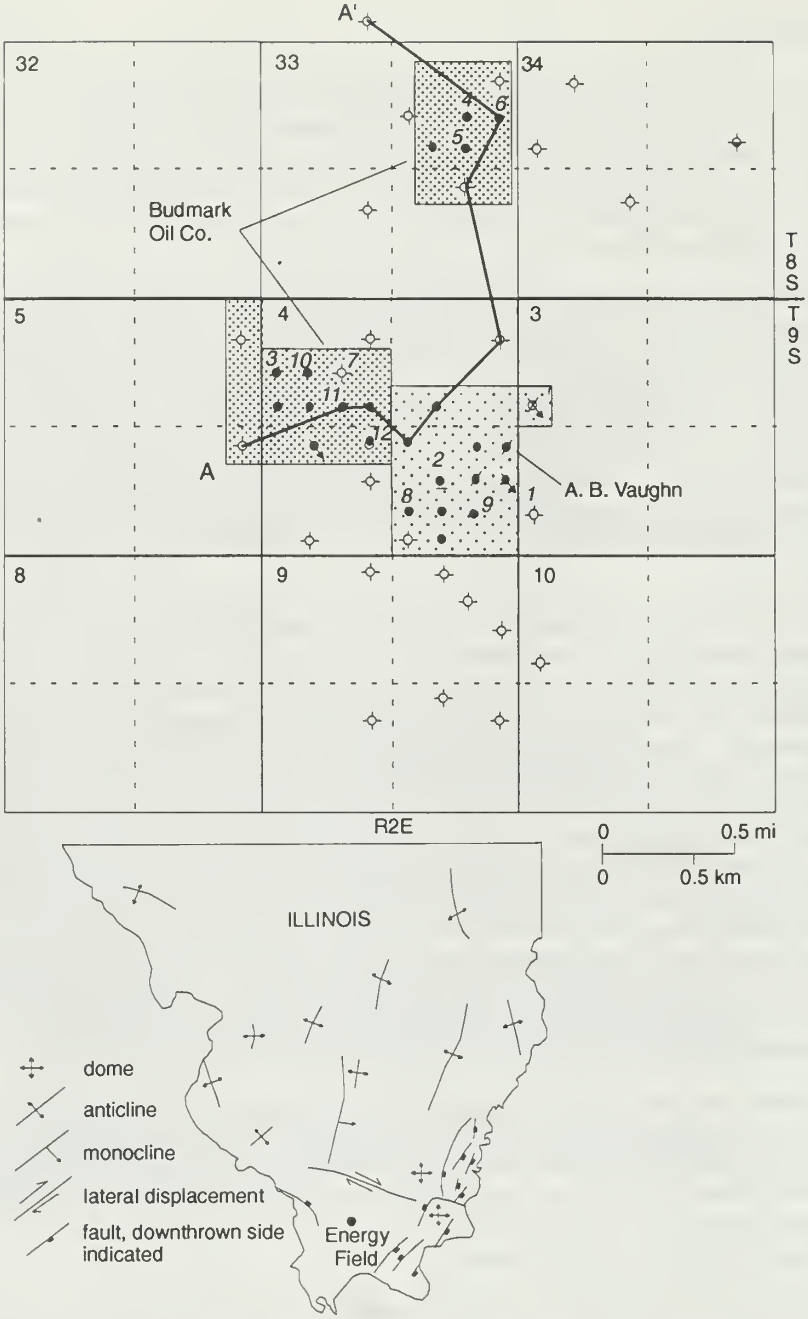


Figure 1 Location of Energy Field. (*top*) Line shows location of cross section A to A' (fig. 9). The discovery well is underlined and the operator's holdings are delineated. Italic numbers identify wells cited in text:

- *1* Calvert Drilling, Morgan Coal No. 1
- *2* A. B. Vaughn, Eovaldi–Fairchild No. 1
- *3* Budmark Oil, Williamson County Airport–Morgan Coal No. 1
- *4–6* Budmark Oil, Burr Oak Nos. 1, 2, and 3
- *7* Budmark Oil, Morgan Coal No. 7
- *8–9* A. B. Vaughn, Hill–Zoller No. 2 and Morgan Coal No. 1
- *10–11* Budmark Oil, Morgan Coal Nos. 3 and 2
- *12* Budmark Oil, Morgan Coal No. 5-A

Production from this field is solely from Aux Vases sandstones. *(bottom)* Small-scale map shows major structural features in southern Illinois.

INTRODUCTION

Energy Field, located 3 miles northwest of the town of Marion and 6 miles south of the Cottage Grove Fault System in Section 4, T9S, R2E, and Section 33, T8S, R2E, Williamson County (fig. 1), contains 220 proven productive acres. Several infill and delineating locations are yet to be drilled within the allowed 10-acre well spacings.

Oil production is from sandstone in the upper Valmeyeran (Mississippian) Aux Vases Formation (fig. 2) at depths of approximately 2,400 feet; it is the southwesternmost location of Aux Vases production in the state. Two upper and two lower sandstone bodies were discovered and developed, giving the field four separate reservoir zones. Over most of the field, the upper sandstone bodies are separated from the lower sandstones by several thin, impermeable, calcareous, argillaceous sands and shales.

The goals of this study were to (1) ascertain and explain the geometry and quality of the Aux Vases reservoirs in the field; (2) relate depositional environments of the reservoir rocks to reservoir continuity, quality, and geometry; (3) estimate the amounts of remaining mobile and recoverable oil reserves; and (4) discuss methods to recover this oil.

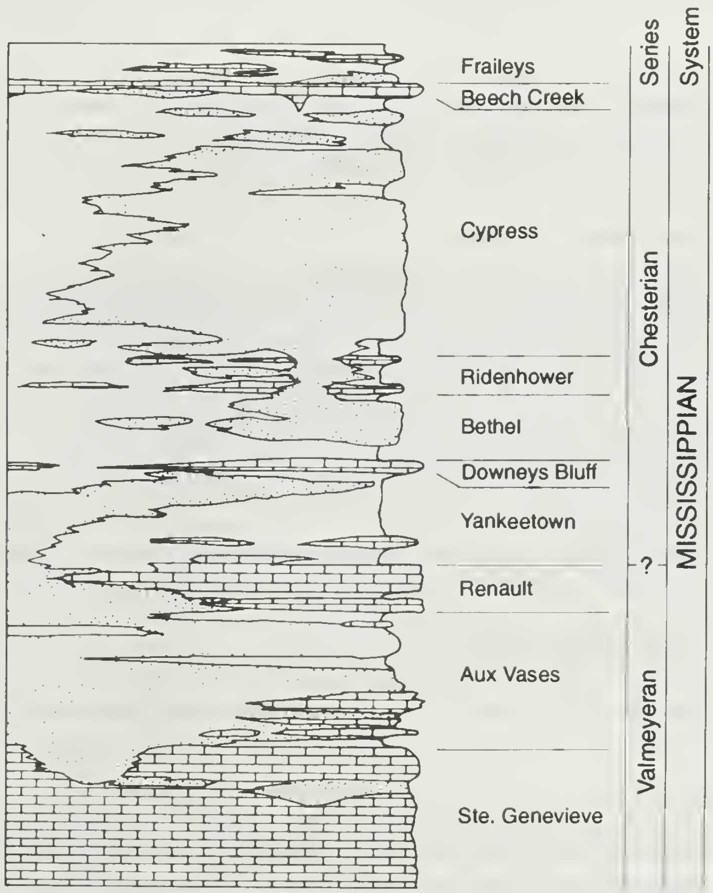


Figure 2 Generalized stratigraphic column for the upper Valmeyeran and lower Chesterian Series in southern Illinois (from Whitaker and Finley 1992).

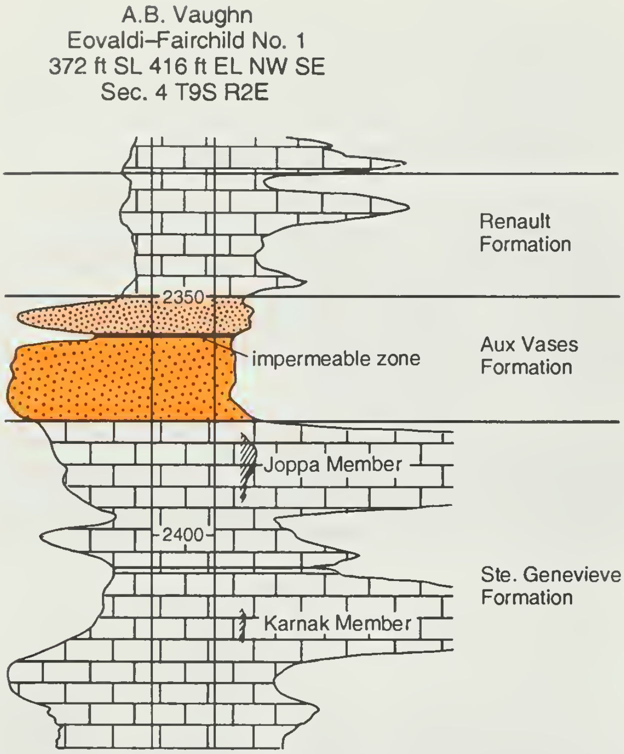


Figure 3 Electric log of the Eovaldi–Fairchild No. 1, the discovery well for Energy Field, illustrates upper and lower sand bodies separated by an impermeable zone.

Discovery History

The first indication of oil in the study area appeared in Calvert Drilling's No. 1 Morgan Coal well, which was drilled in September 1955. The well swabbed oil at a rate of 1.5 barrels of oil per hour from the Joppa Limestone Member of the Ste. Genevieve Limestone (Swann 1963) (fig.2) before being plugged and abandoned in October 1955. The field discovery occurred in June 1968 when A. B. Vaughn's Eovaldi–Fairchild No. 1 well, approximately 1/2 mile west of the No. 1 Morgan Coal well, was drilled to a depth of 2,442 feet and encountered two distinct bodies of clean Aux Vases sandstone between 2,352 and 2,377 feet deep (fig. 3). The well was perforated between 2,354 and 2,370 feet and initially produced 15 barrels of oil per day (BOPD). In October 1968, the well was hydraulically fractured and production increased to 40 BOPD and 40 barrels of water per day (BWPD) (Moore 1969).

Production History

The field has undergone four stages of development. The first stage lasted from 1968 to 1969, during which ten oil wells were drilled in the southeast quarter of Section 4.

In the second stage of development, a secondary recovery project utilizing one peripheral, water injection well was initiated in October 1971 to repressure the reservoir. Unitization was accomplished by January 1972, and the reservoir was repressured to 1,300 psia by the end of that year. By December 1972, production had risen to more than 3,000 BO per month—three times the primary recovery rate (fig. 4). The large increase in production was short-lived, however, and fell to lower levels by November 1973 (fig. 4). The performance of this project probably was

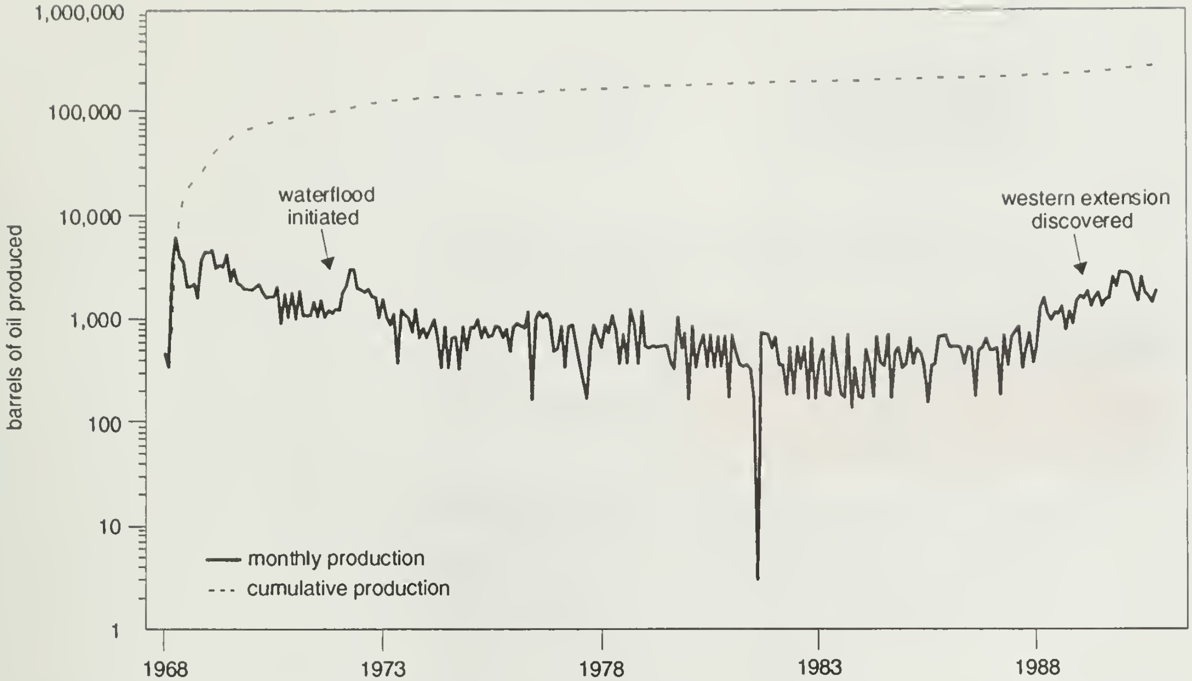


Figure 4 Monthly and cumulative production of Energy Field. Note increased production shortly after waterflood inception and discovery of the western extension.

hampered by use of surface water that had leached through coal mine tailings mixed with produced brine as the injection fluid. This mixture seems to have been chemically active within the reservoir and caused formation damage that lowered the recovery rate (Bob Walker, Walker Engineering, personal communication 1990). At the end of 1989, a total of 168,500 barrels of water had been injected; 93,052 barrels of water and 237,658 barrels of oil had been produced.

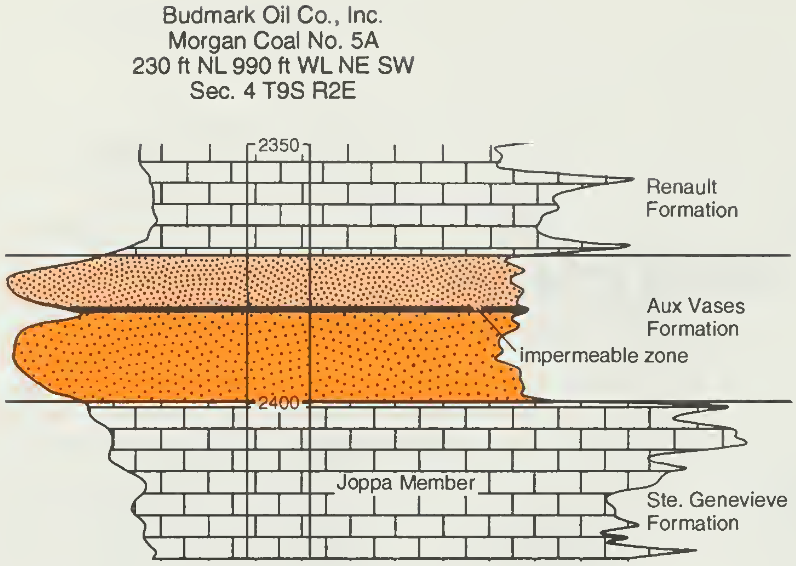
The third stage of development began in July 1988 when the Budmark Oil Company completed its No. 1 Williamson County Airport–Morgan Coal well for 22 BOPD and 75 BWPD. The well is in the NW SW NW, Section 4, and extended the field limits more than 1/2 mile to the west. During this stage, which lasted until June 1990, nine oil wells and three dry holes were drilled in the west half of this section. The latest development in the field was in Section 33, T8S, R2E, with the completions of the Burr Oak Nos. 1, 2, and 3 wells by Budmark Oil Company, which extended the field limits 1 mile to the north.

At this writing, two other locations in the field have been permitted for drilling. Of the 22 oil wells drilled to date, 18 are still producing, two were converted to saltwater injection, and the original injection well was plugged. As of January 1992, the field had a cumulative production of more than 306,000 BO and was producing 150 BOPD.

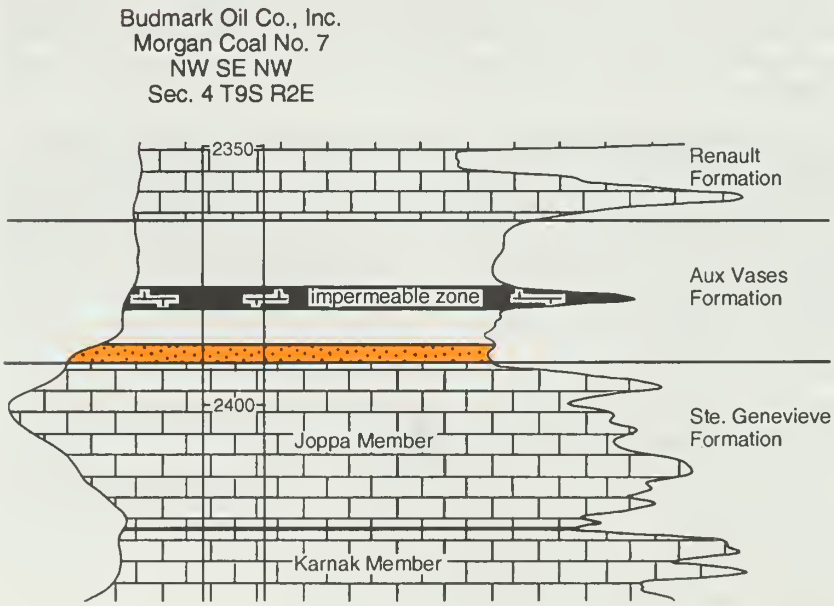
RESERVOIR AND TRAP CHARACTERISTICS

Stratigraphy

The Aux Vases Formation at Energy Field ranges from 30 to 50 feet thick and consists of interlayered sandstones, shales, calcareous sandstones, and limestones (figs. 5a–d). The formation is underlain by the Joppa Member of the Ste. Genevieve Formation, which is about 25 feet thick, and conformably overlain by the basal limestone of the Renault Limestone, which can be up to 9 feet thick. This basal

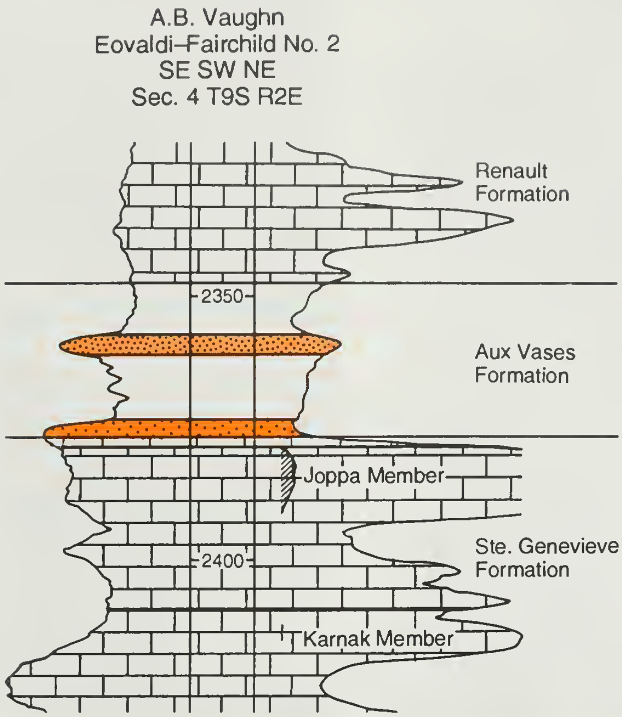


5a

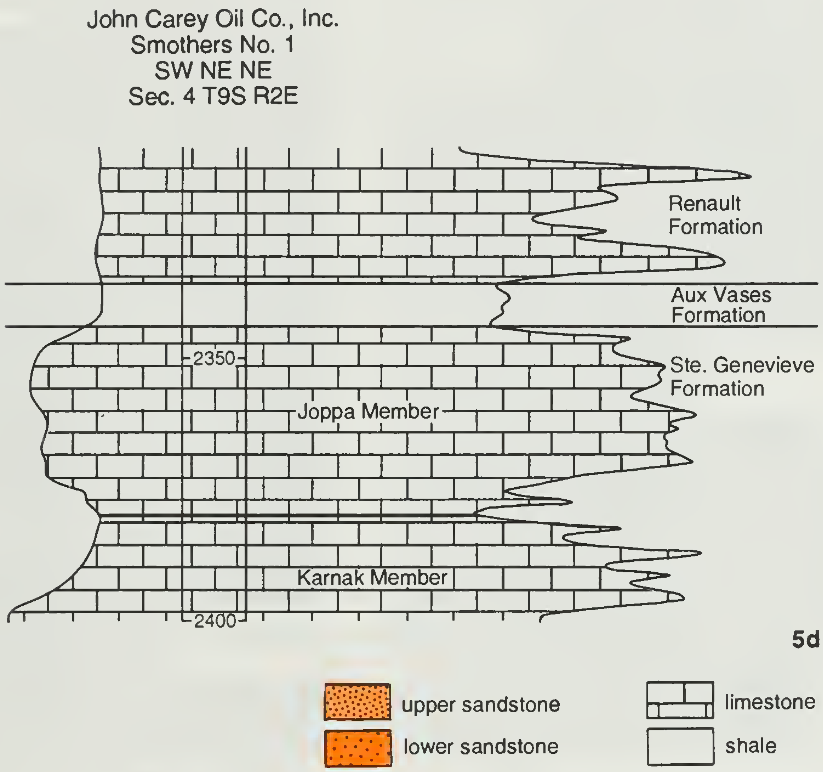


5c

Figure 5 Log responses and lithofacies from Energy Field.


A.B. Vaughn
Eovaldi–Fairchild No. 2
SE SW NE
Sec. 4 T9S R2E
Renault Formation
2350
Aux Vases Formation
Joppa Member
Ste. Genevieve Formation
2400
Karnak Member

5b


John Carey Oil Co., Inc.
Smothers No. 1
SW NE NE
Sec. 4 T9S R2E
Renault Formation
Aux Vases Formation
Ste. Genevieve Formation
2350
Joppa Member
Karnak Member
2400
upper sandstone
lower sandstone
limestone
shale

5d

Renault Limestone is absent in a small area in Section 33 where deposition did not occur on the topographic highs formed by thick Aux Vases sandstones.

Figures 5a–d show various electric log responses for the field area and the major lithofacies of the economically important siliciclastic zone within the Aux Vases Formation. The lithofacies include the (1) lower sandstone bodies, (2) thin impermeable zone, (3) upper sandstone bodies, and (4) interfingering shale. The lithologic subdivisions, originally defined on the basis of geophysical log characteristics, were subsequently confirmed by a core recovered in December 1991 from the Budmark Oil Company's Burr Oak No. 3 well in the NE SE NE, Section 33, T8S, R2E. Samples of the upper and lower sandstones and the thin impermeable zone were recovered. No samples of the interfingering shales have been taken to date. The core is illustrated in plates 1–6, and described in appendix E and figure E-1.

The upper sandstone bodies are thin, usually 4 to 5 feet thick, and occur in the field as two discrete pods 3/4 mile apart; each is approximately 3/4 mile long and 1/2 mile wide. In a small area in the center of Section 4, T9S, R2E, the sandstone thickens to 10 feet (fig. 6), but it pinches out abruptly to the west. On electric logs, the upper sandstone bodies are characterized by a moderate to high SP deflection and a relatively high resistivity (figs. 3 and 5a–b). The sandstone body has a convex-upward shape.

The thin impermeable zone separating the upper and lower sandstone bodies consists of numerous thin beds of shale, siltstone, and very fine grained, algal sandstones. It is up to 4 feet thick and occurs as lenses with limited areal extent (fig. 7). This interval is the major vertical barrier to permeability in the field; it is characterized on electric logs by a suppressed SP and an increased resistivity reading (fig. 5a). In the Morgan Coal No. 7 (fig. 5c), this interval is surrounded by interfingering shales of very low resistivity and SP. In this well, the beds in the thin impermeable zone exhibit a sharp increase in resistivity relative to the interfingering shales. A neutron log through this interval in Budmark's Morgan Coal No. 5-A recorded a decrease in porosity to about 6% for the thin impermeable zone, and core analyses from Budmark's Burr Oak No. 3 show permeabilities of 0.1 millidarcies (md) or less.

The lower sandstone occurs in two discrete pods approximately 3/4 mile apart. Each pod may be up to 24 feet thick (fig. 8). Logs of this interval (figs. 3 and 5a–c) show high SP deflections and low resistivities. Both lower sandstone bodies are convex upward in cross section (fig. 9). The southern sandstone body, which is 1 mile long and 3/4 mile wide, trends east-west; whereas the northern sandstone body is 1 mile in maximum dimension and has no apparent orientation.

Shale units that interfinger with all these sandstone bodies are up to 30 feet thick. Characterized by low SP and resistivity values (figs. 5b–d), these shales laterally seal the sandstones and, coupled with the thin impermeable zone, effectively isolate the four sandstone bodies into separate reservoirs.

Electric log correlations (fig. 9) show the spatial relationships of these lithologies, particularly the compartmentalization of the four reservoir sandstones. Figure 1 shows the location of this cross section through the field.

Structure

A structure map contoured on the base of the Renault Limestone (fig. 10) shows a structural nose underlying Section 4, T9S, R2E; it is 1 mile wide and plunges to the northwest. Oil wells are located along the broad crest of this structure, but at some of the highest elevations, dry holes indicate the absence of reservoir sandstone. Control points outside the field are sparse, and regional mapping reveals a relatively

Plate 1 Core through Aux Vases siliciclastic interval (2,392.5 to 2,420.1 feet, Budmark Oil Company, Burr Oak No. 3 well, NE SE NE, Section 33, T8S, R4E). See appendix E for description.

Plate 2

10 cm

Plate 3

Plate 4

Plate 2 Core showing channel and coarse grained bioclastic fill (indicative of exposure) in the thin impermeable zone or tidal flat facies (depth 2,395.4 feet, Budmark Oil Company, Burr Oak No. 3 well). The thin, green, relatively coarse sandstone at the top may represent the transition from intertidal to subtidal deposition.

Plate 3 Core showing tidal deposition features, rhythmites, reactivation surfaces, and crossbedding accentuated by staining of dead oil in the lower sandstone (depth 2,014 feet, Budmark Oil Company, Burr Oak No. 3 well).

Plate 5

Plate 6

Plate 4 Core showing reverse current bedding (indicative of tidal deposition) in the lower sandstone (depth 2,411 feet, Budmark Oil Company, Burr Oak No. 3 well).

Plate 5 Core showing algal stabilization of the lower bar (depth 2,397.3 feet, Burr Oak No. 3 well). Note sharp contact, algal laminations, oncolites, and algal intraclasts.

Plate 6 Core showing oil-filled ichnofossils, *Conostichus* sp. and *Asterosoma* sp. of the *Cruziana* ichnofacies (indicative of a shallow, marine subtidal environment), in the upper sandstone (depth 2,393.5 feet, Burr Oak No. 3 well).

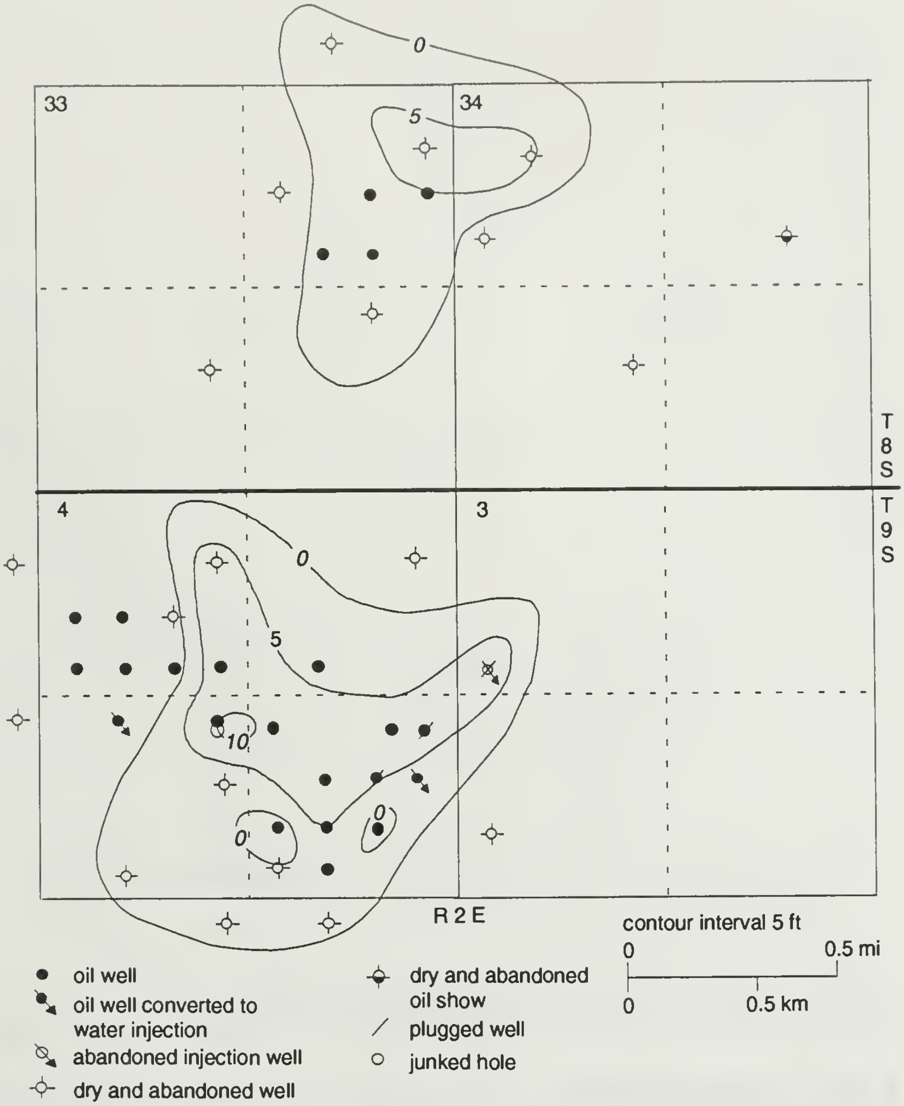


Figure 6 Thickness map of the upper sandstone, Energy Field.

featureless, northward-dipping ramp that rises to the outcrop belt about 30 miles to the south.

To the north, in the east half of Section 33, T8S, R2E, is a northward-plunging nose 1/2 mile wide. Although a producing oil well defines the highest area on this structure, the most productive well in the section is one location to the north and 20 feet structurally lower. This relationship demonstrates that productive wells in the field depend more on the presence of thick sandstone reservoirs than on their structural position.

PRODUCTION CHARACTERISTICS

Oil Characteristics

Oil samples were collected for analysis from three wells in the southern part of the field. These analyses are presented in appendixes A, B, and C. API gravity of oil from this field averaged 39.4° at 60°F; viscosity is 3.9 cp at 60°F.

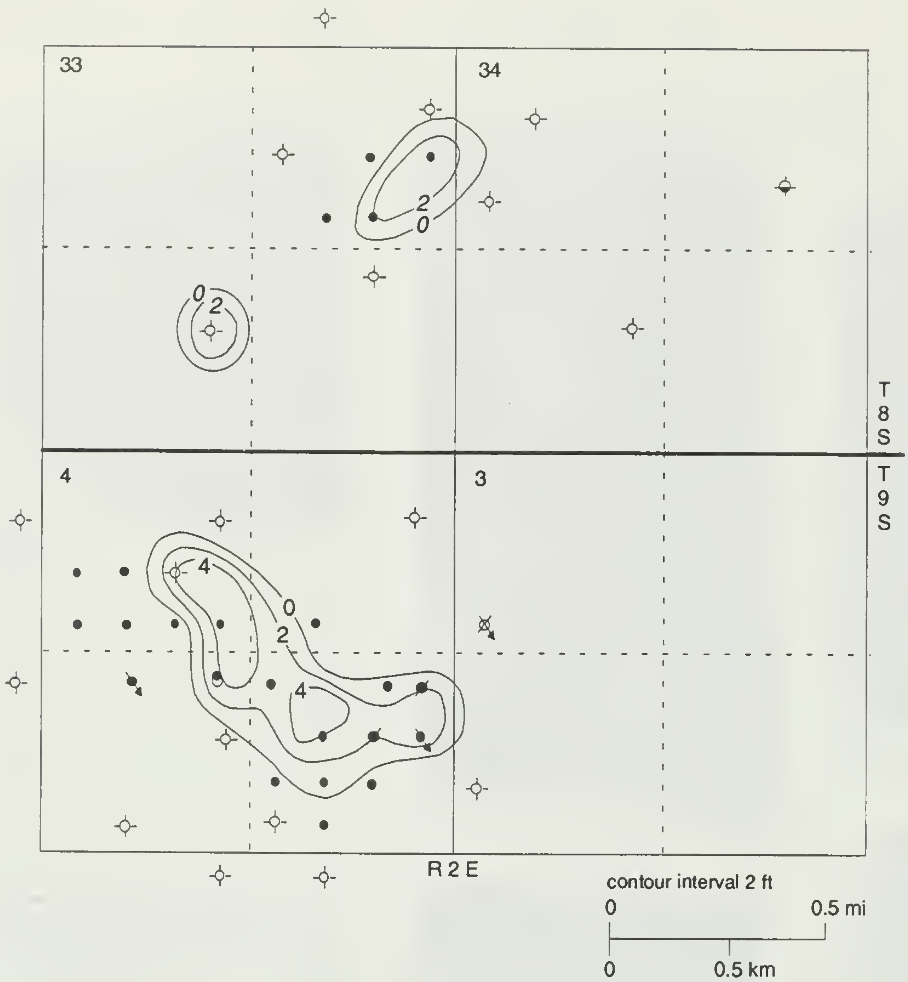


Figure 7 Thickness map of the thin impermeable zone, Energy Field.

Water Characteristics

Brine samples were collected from five wells in the southern part of the field. The sampled wells include the three that were sampled for oil and two other wells that yielded only water when well bore fluid was collected. The brine chemical analyses are shown in appendixes A and C. Brine resistivities measured at the wellhead at 77°F were .063 ohm meters. Mathmatically correcting this value to the reservoir temperature of 84°F (appendix A) yields a resistivity value of .058 ohm meters.

Drilling and Completion Practices

Rotary tools and freshwater bentonite mud were used to drill all the wells in the field. The most widespread completion practices consisted of cementing a long string of casing through the zone of interest, perforating the casing, and cleaning the hole out with 250 to 500 gallons of 15% mud cleaning acid (MCA). The well was then hydraulically fractured with gelled water and sand proppant in amounts varying from 500 to 12,000 gallons of water and 500 to 16,000 pounds of sand. None of the wells flowed naturally and all were put on pump. Two of the early wells in the field, the Hill–Zoller No. 2 and the Morgan Coal No. 1, had casing set on top of the producing

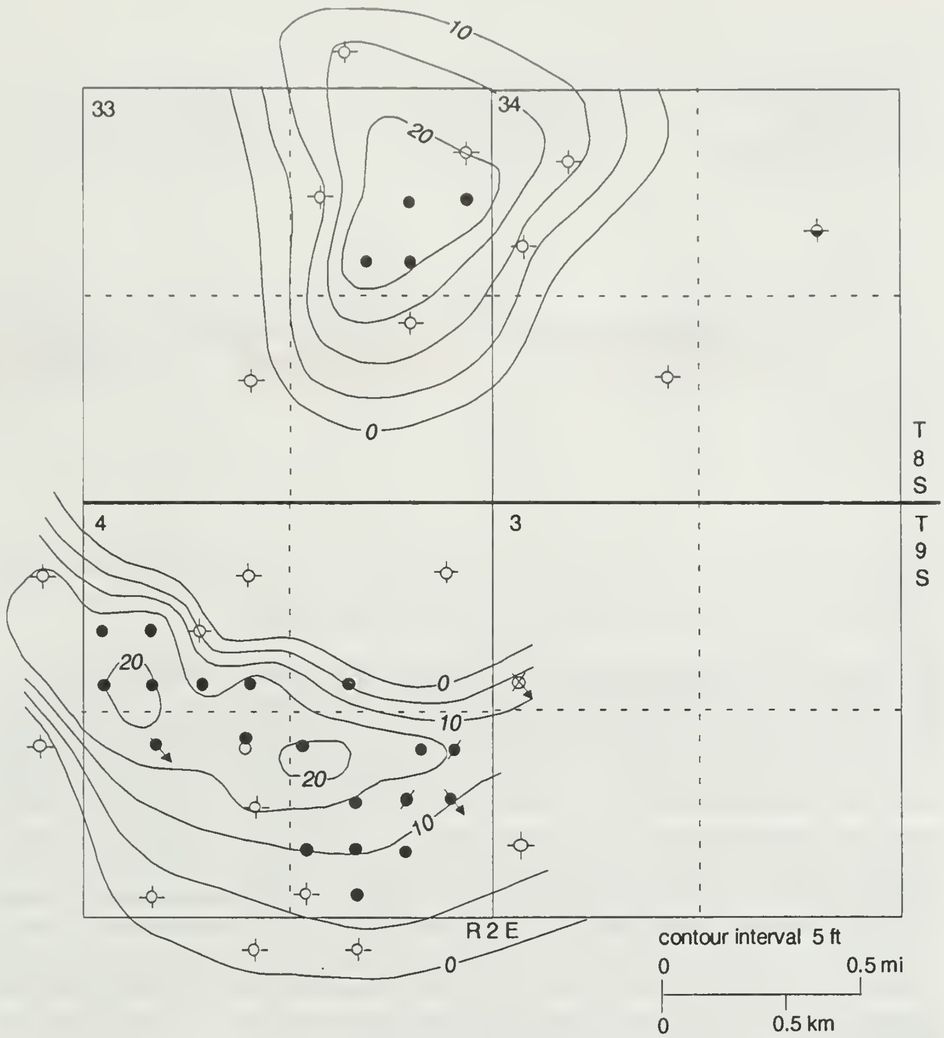


Figure 8 Thickness map of the lower sandstone, Energy Field.

zone, and then were fractured with 20 quarts of nitroglycerine. The initial production figures for these wells were 80 and 40 BOPD, respectively, and no water.

During the development of the northwest quarter of Section 4, T9S, R2E, it was suspected that MCA treatments were damaging the reservoir because fluid production rates had dropped substantially after treatment of the Morgan Coal No. 3 well with MCA (Hiram Hughes, Budmark Oil, personal communication 1990). Subsequently, four more wells were drilled on the lease and hydraulically fractured, but MCA was not used.

Lease oil was used to fracture the Burr Oak No. 1 well in an effort to reduce formation damage during the most recent field development. During completion of the Burr Oak No. 2 and Burr Oak No. 3 wells, drilling mud was perceived to be clogging pores, and fluid production was falling (Jim Dunston, Budmark Oil, personal communication 1991). Conditions warranted the use of MCA. The three Burr Oak wells were treated with 7.5% MCA, which apparently did not decrease fluid production (Hiram Hughes, Budmark Oil, personal communication 1992).

A

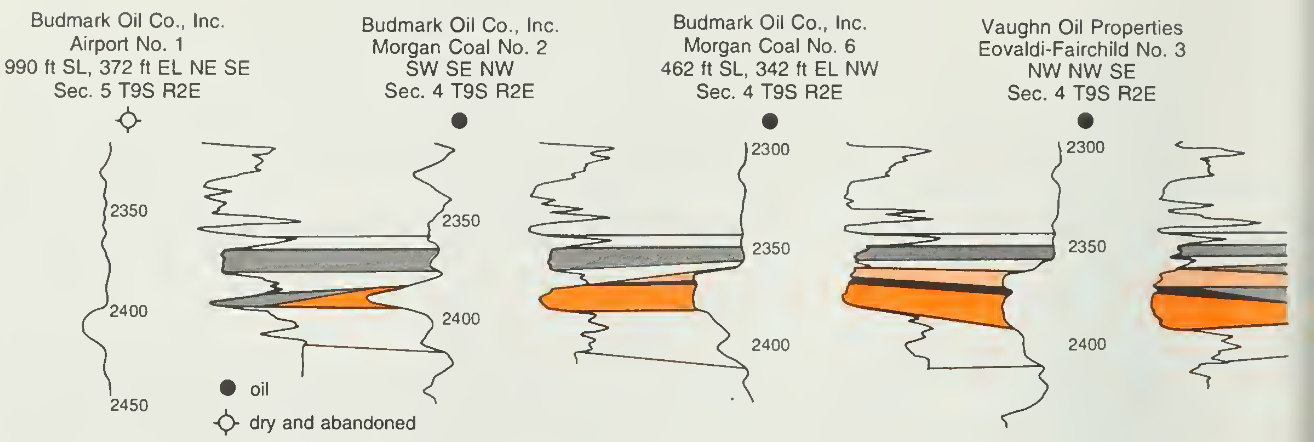


Figure 9 Stratigraphic cross section A to A′ (shown on fig. 1). Note compartmentalization of the sandstones (upper reservoir sandstone, light orange; lower reservoir sandstone, dark orange; impermeable zone, black; shales, gray; limestones, white).

Production Characteristics of Upper and Lower Sandstones

Both the upper and lower sandstones of the Aux Vases Formation are productive. Cumulative primary production totals on the A. B. Vaughn holdings and current cumulatives on the Budmark Oil Company leases through October 1991 show that the most productive wells in the south part of the field have more than 10 feet of reservoir sandstone above the oil–water contact. The lower sandstone is the primary reservoir in most of these wells because the upper sandstone is either thin or absent (figs. 6 and 9). In the center of section 4, however, the upper sandstone is thick and a structural saddle places most, if not all, of the lower sandstone below the oil–water contact. The Morgan Coal No. 5-A (NE NE SW, Section 4, T9S, R2E), completed in the upper sandstone during late April 1990, shows that with favorable structural position and thickness the upper sandstone can be quite productive. More than 10,000 BO have already been produced.

RESERVES AND REMAINING RECOVERABLE OIL

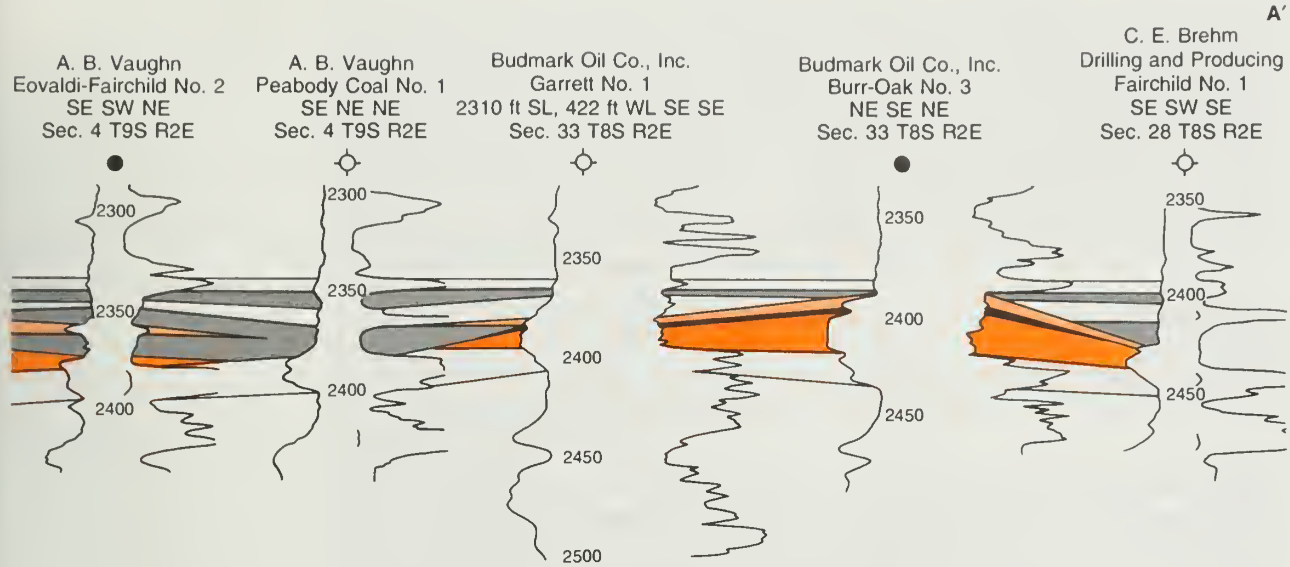
Reserve calculations for the field were made for each reservoir sandstone using the following equation:

$$\text{OOIP} = 7758 \times H \times A \times \phi \times (1 - S_w)$$

where

7758 = conversion factor for acre-feet to barrels
H = height (in feet) of net reservoir sandstone
A = area (in acres) of net reservoir sandstone
ϕ = average porosity of reservoir sandstone
S_w = water saturation of reservoir sandstone

Core analyses from three wells in the southern portion of the field were available for reserve calculations of the southern sandstone bodies; but only one core analysis was available for reserve calculations for the northern sandstone bodies. Values for S_w and ϕ for each of the four sandstone bodies were averaged from the core analyses (appendix A). The S_w values calculated from induction logs were not used



because R_t values on the order of 1 to 3 ohm-meters are considered to be erroneously low. These low resistivity values are believed to be caused by the presence of clay-bound water (Seyler 1988). The area and thickness of net reservoir sandstone for the four reservoirs were calculated from isopach maps. Results of the OOIP calculations are presented below.

South sandstone bodies:

Upper sandstones: 7758 × 1,240 acre feet × 0.1876 × 0.478	= 863,000 BO
Lower sandstones: 7758 × 1,795 acre feet × 0.2070 × 0.492	= 1,418,000 BO

North sandstone bodies:

Upper sandstones: 7758 × 578 acre feet × 0.2010 × 0.581	= 524,000 BO
Lower sandstone: 7758 × 1,912 acre feet × 0.2110 × 0.511	= 1,599,000 BO
Total OOIP	4,404,000 BO

To calculate the stock tank original oil in place (STOOIP), divide the OOIP by the formation factor (B_{oi}), which for this field is 1.10 (Moore 1969):

STOOIP = 4,404,400 BO ÷ 1.10 = 4,004,000 BO

In a preliminary engineering study of the A.B. Vaughn Oil Properties holdings in this field (Moore 1969), a primary recovery rate of 9.8% and a secondary recovery rate of 15.9% of total field reserves were predicted. The low primary recovery was attributed to an inefficient solution gas drive, shallow depth (and therefore low pressure), and energy dissipation through water production. The field was waterflooded after production of 95,000 BO or 7.3% of STOOIP from this lease. A decline curve projected through water-out shows an ultimate recovery of 271,800 BO from this lease or 20.9% of the calculated STOOIP. Projecting this performance for the rest of the field gives a primary production of 292,000 BO (7.3% of STOOIP) and secondary reserves of 545,000 BO (13.6% of STOOIP). Subtracting the amount of oil already produced from the field to date from the recoverable reserves leaves an estimate of remaining recoverable reserves of 531,000 BO.

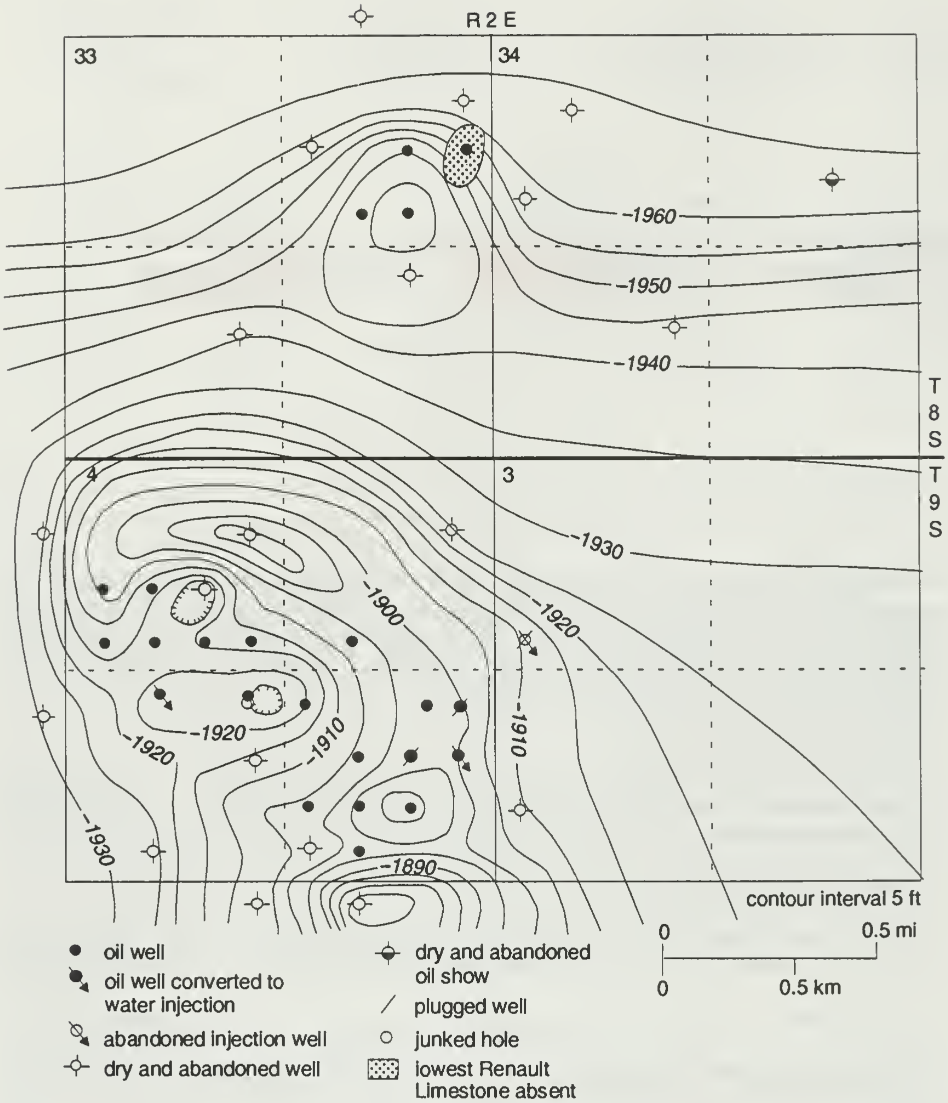


Figure 10 Structure contour map on the base of the Renault Limestone. This limestone is absent in a portion of Section 33.

PETROGRAPHY

Two cores and one core biscuit from three different wells were available for petrographic analysis from Energy Field. Twenty-one thin sections were prepared and examined from this material. Samples were analyzed by optical petrography, scanning electron microscopy (SEM) with energy dispersive X-ray (EDX), and X-ray diffraction (XRD).

Analyses of thin sections taken from available cores show that the lower sandstone of the Aux Vases Formation consists of a fine and very fine grained arenite with quartz grains constituting 85% of the rock. Feldspars make up to 5% of the rock. The grains are subangular to subrounded; quartz overgrowths account for some of the grain angularity seen in thin sections. SEM imagery shows the growths are actually patchy and isolated. Fossil fragments consisting of echinoderm plates

(primarily crinoid columnals), bryozoans, and brachiopod spines are common, and some fragments show pressure solution caused by pressure from adjacent quartz grains. The grains are differentiated by size in layers several millimeters thick. Grains with prominent long axes are preferentially oriented along bedding surfaces. Accessory minerals consist of zircon, tourmaline, muscovite and biotite. Rare lithic clasts also occur. The major porosity is primary interparticle, enhanced to a minor degree by dissolution of feldspars. Cements in this facies (plates 7 and 8) are of four types: (1) clay coatings on grains, (2) quartz overgrowths, (3) syntaxial calcite cement, and (4) interparticle microcrystalline calcite cement.

Interparticle porosity is abundant and occlusion by cement is rare, although in very small areas it may be total. The porosity of this sandstone ranges from 13.6% to 24.1% and averages 20.4%. Vertical permeability values range from 2.1 to 146.0 md and average 45 md. The average horizontal permeability is 78 md, and values range from 4.3 to 257.0 md.

SEM imagery and EDX analysis of the lower sandstone show chlorite flakes covering the sand grains (plate 8). Another clay, fibrous illite, is rare but occurs in some pores (plate 8). X-ray diffraction (appendix D) shows a total clay content averaging 4.6%. Late stage quartz overgrowths and calcite crystals have incorporated previously formed clay flakes into their structure, or have grown around the flakes, thus indicating that these cements formed after clay precipitation. Secondary anatase and a calcite ooid were detected with the SEM but are exceptionally rare.

The upper sandstone consists of 80% very fine and silt-size grains of subangular monocrystalline quartz, 5% fecal pellets, and 5% to 10% feldspar grains; the balance of the rock consists of fossil fragments and accessory minerals. Bioclasts consist of crinoid columnals and bryozoan fragments. Accessory minerals observed include zircon, tourmaline, muscovite, and amphibole. The grains are cemented by chlorite clay flakes and abundant, but patchily distributed, quartz overgrowths. A large amount of the pore space has been occluded by a calcareous, crystalline clay cement so pervasive that clasts appear as floating grains (plate 9). Porosity is primary interparticle, enhanced by feldspar dissolution. Porosity and permeability occur only in areas where the cement has been dissolved or is sparse. Porosity in this sandstone ranges from 15.1% to 21.3% and averages 19.5%. Horizontal permeability values range from 1.3 to 20.0 md, averaging 19.0 md; vertical permeability values range from 0.29 to 15.0 md and average 13.0 md. The relatively low permeabilities of the upper sandstone are attributed to their fine particle size and widespread cement. The sand is notably bioturbated, as evidenced by numerous burrows observed in thin section.

SEM imagery of the upper sandstone (plate 10) reveals chlorite clay flakes covering the grains; fibrous illite is rare. The imagery confirms the smaller grain size of the upper sandstone, as compared to the lower sandstone, and the presence of large amounts of cement occluding pores and pore throats (plate 11). The effect is to reduce permeability. Degradation of feldspars is a possible source for the crystalline clay cements, but the quantity of cement observed suggests recrystallization of clay originally deposited in the rock.

DEPOSITIONAL SETTING

The petrographic evidence and regional setting indicate that the lower Aux Vases sandstone bodies in Energy Field were deposited as progradational, marine tidal bars (fig. 11a) or ridges (Off 1963). Evidence for this interpretation includes

- convex upward morphology (fig. 9);

- core (plates 3 and 11) and thin sections (plates 3 and 11) containing tidal rhythmites, representing ebb and flow deposition;
- core showing bidirectional crossbedding (plate 4), indicating two directions of transport;
- upward-coarsening of bar sandstone on top of finer grained distal marine sandstone (plate 1);
- bimodal grain size distribution, representing two dominant depositional regimes (ebb and flow) (plates 7 and 11);
- marine fossils in cores and thin sections.

These bars are interpreted to have been deposited as sand wave forms, as indicated by their occurrence at regular intervals (see section, Identification and Classification of Play).

As relative sea level fell, topographically high areas became semi-emergent, changing the depositional environment and facilitating accumulation of the sediments that form the thin, impermeable zone. Erosion was prevented in these areas as the shallowing water allowed algal mats to grow (plates 1 and 5) and the substrate to stabilize. Shallow marine tidal flat sediments then accumulated in the areas subject to intertidal deposition (fig 11b) and covered the algal mats. Subtidal deposition of shales (fig. 11b) would allow the formation of the highly resistive emergent facies on top of shale aprons covering sand bars, as observed in the log signature of the Morgan Coal No. 7 well (fig 5c). This interpretation is based on the following observations:

- the areal extent and repeated occurrence of this sequence of sediments (identifiable on logs as the thin impermeable zone) primarily on top of the thicker lower sandstone (topographically highest) in both the north and south bar complexes (fig. 7);
- nondeposition of these sediments between bar complexes (topographically lower and not subject to intertidal deposition) (fig. 7);
- presence of algal mats overlying the lower bar with a very sharp gradational contact, as observed in core (plate 5);
- sedimentary structures indicative of exposure (curled shale chips, oncolitic and shale intraclasts, and penecontemporaneous channeling and filling) visible in core (plates 2 and 5, appendix E).

These sediments record deposition during the sea level lowstand in this area.

An alternative explanation for the tidal flat deposits on top of rhythmic tidal ridges is provided by Off (1963, p. 328) for sediments that can be observed today near the mouth of the Amazon River. In Off's opinion, "the ridges have built up above the normal tide level, permitting silt and mud to settle out at slack water during the spring high tides....A drill hole into these ridges should show sand-sized particles under a thin mud cover." That a similar mechanism had some impact on the sediments observed in the thin impermeable zone cannot be ruled out. In either case, these deposits are the result of a relative lowering of sea level that allowed tidal flats to accumulate on top of the ridges.

The event initiating the formation of the upper sandstone bodies was the marine transgression eventually leading to the deposition of overlying Renault limestones. The upper sandstones are interpreted as having developed in a subtidal, shallow marine environment where the topographically high areas formed by the lower bars accommodated subtidal winnowing of sediments by wave action (figs. 11c and 12).

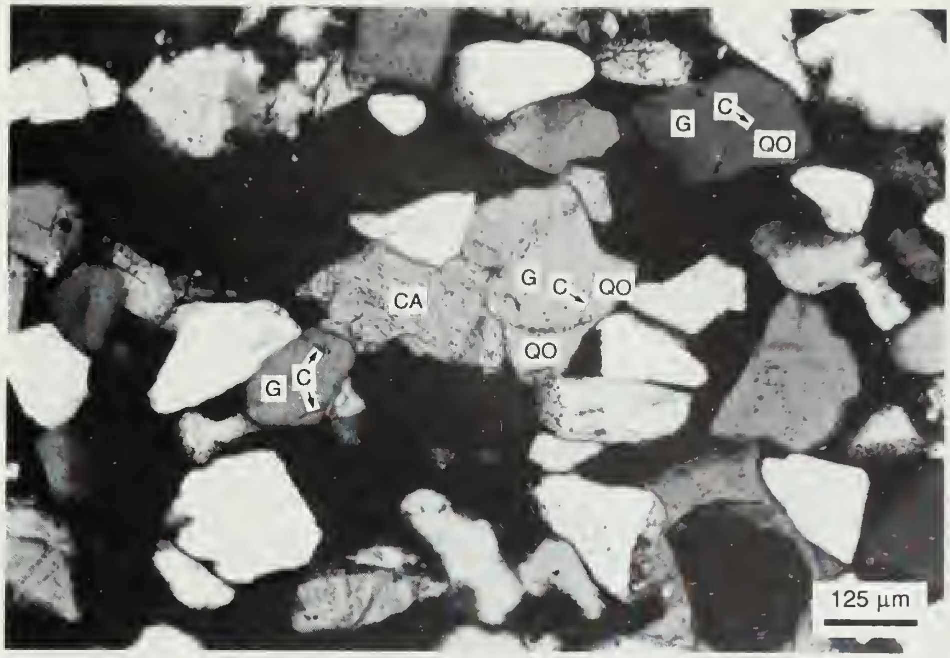


Plate 7 Photomicrograph of lower sandstone showing cementation (depth 2,388.4 feet, Budmark Oil Company, Morgan Coal No. 2 well). The original clay rim cement (C) is observed coating the original grain (G) boundary. These have been incorporated into quartz overgrowths (QO). Crystalline calcite cement (CA) has replaced the quartz overgrowths and the original grains, while incorporating the clay rim cement into its structure. Nicols crossed, 100×.

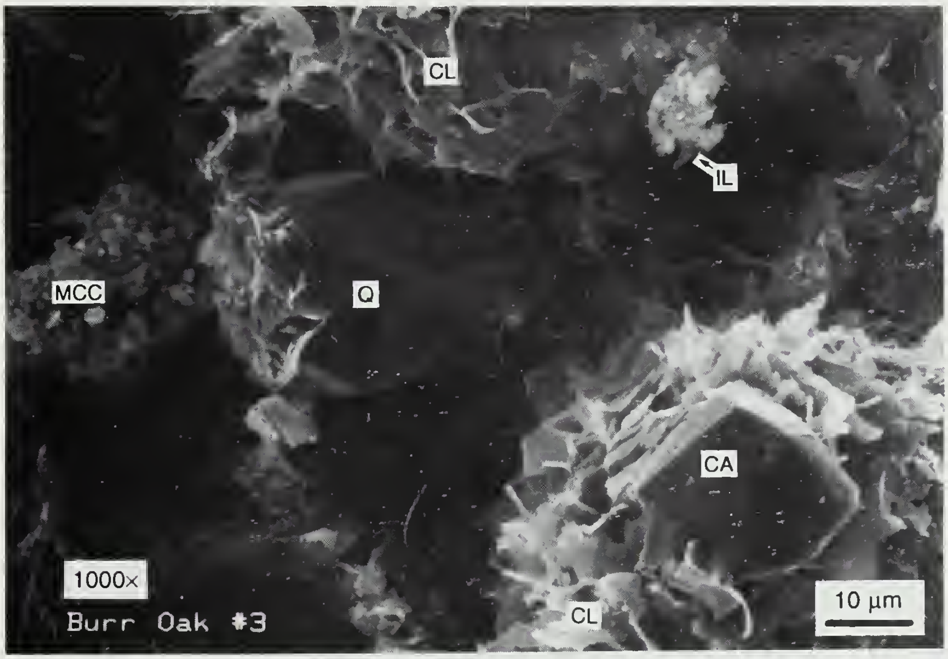


Plate 8 SEM image of lower sandstone (depth 2405.2 ft) showing chlorite clay coatings (CL), illite (IL), quartz overgrowths (Q), microcrystalline calcite cement (MCC), and crystalline calcite cement (CA). Budmark Oil, Burr Oak No. 3 well.

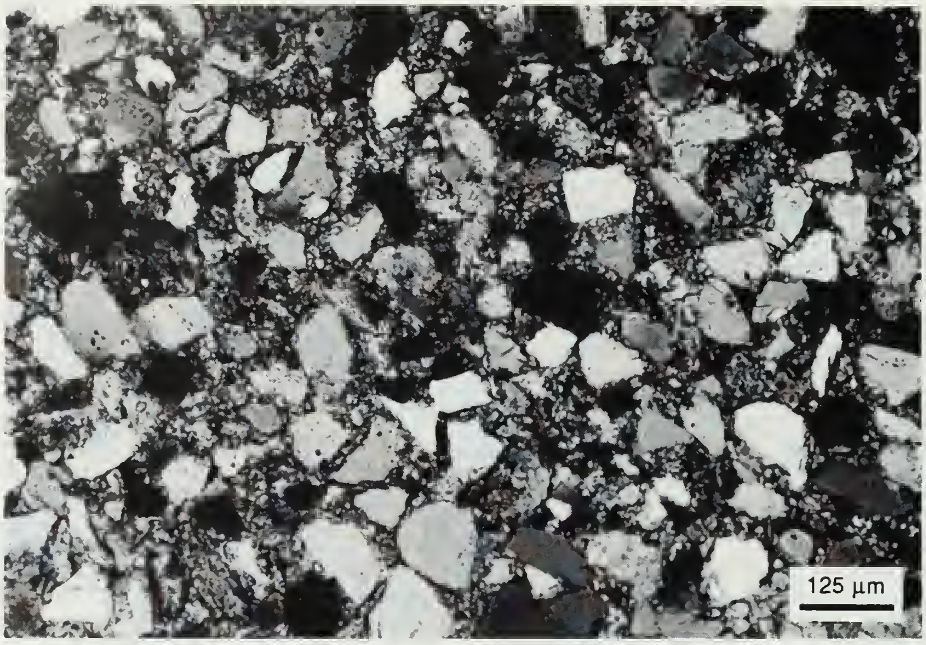


Plate 9 Photomicrograph of the upper sandstone (depth 2,394 feet, Budmark Oil Company, Burr Oak No. 3 well). Note total occlusion of porosity and permeability by crystalline clay cement, and floating quartz grains. Compare grain size to that of lower sandstone in plate 7, which is the same magnification. Nicols crossed, 100×.

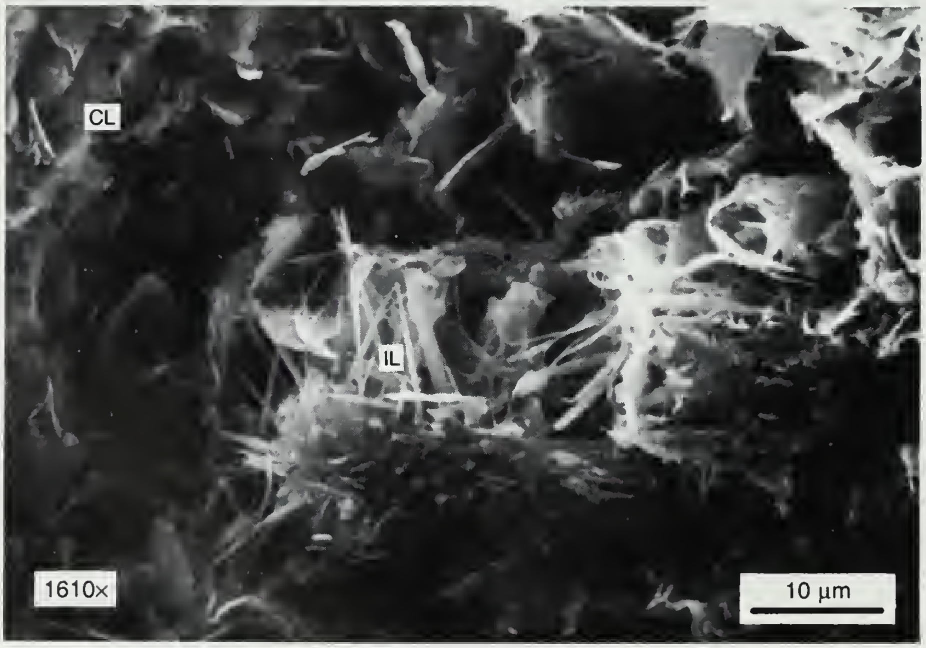
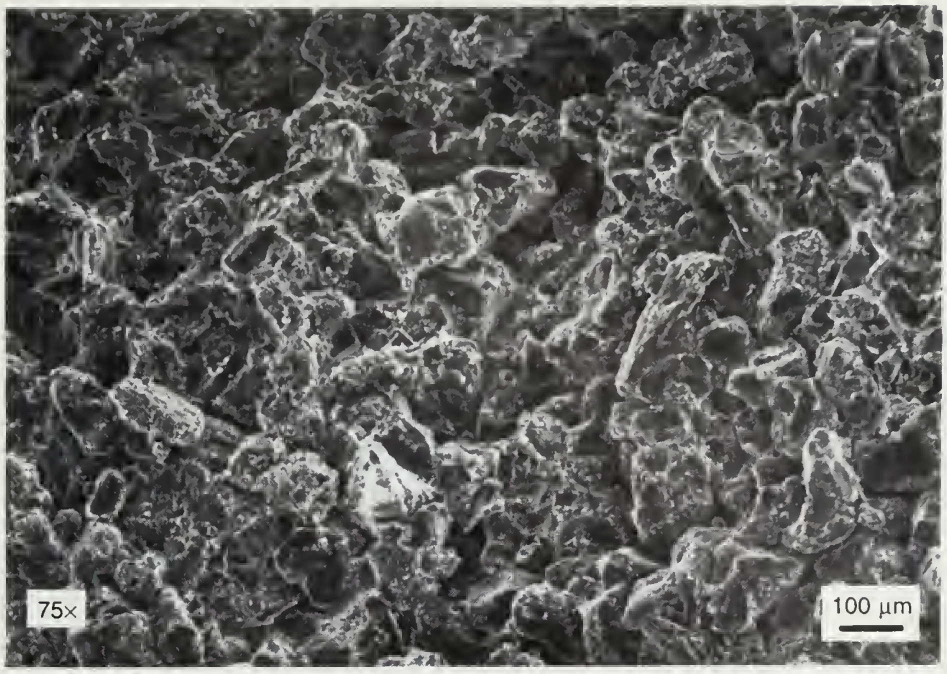


Plate 10 SEM image of upper sandstone (depth 2393.5 ft) showing chlorite clay coatings (CL), and fibrous illite (IL). Budmark Oil, Burr Oak No. 3 well.

a



b

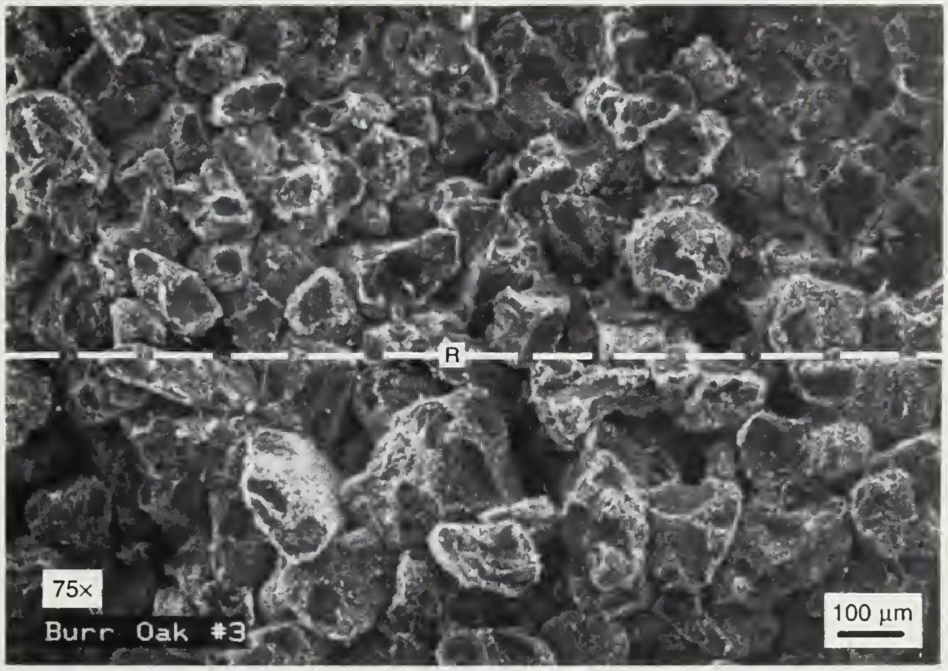


Plate 11 Comparison of low magnification SEM images of a) at 2393.5 ft depth, upper sandstone, and b) at 2405.2 ft depth, lower sandstone. Note difference in grain sizes and upper sand porosity occlusion by cement. A rhythmite sequence (R) is visible in the lower sandstone. Surface separates fine grained sand from coarse grained sand in lower portion of image.

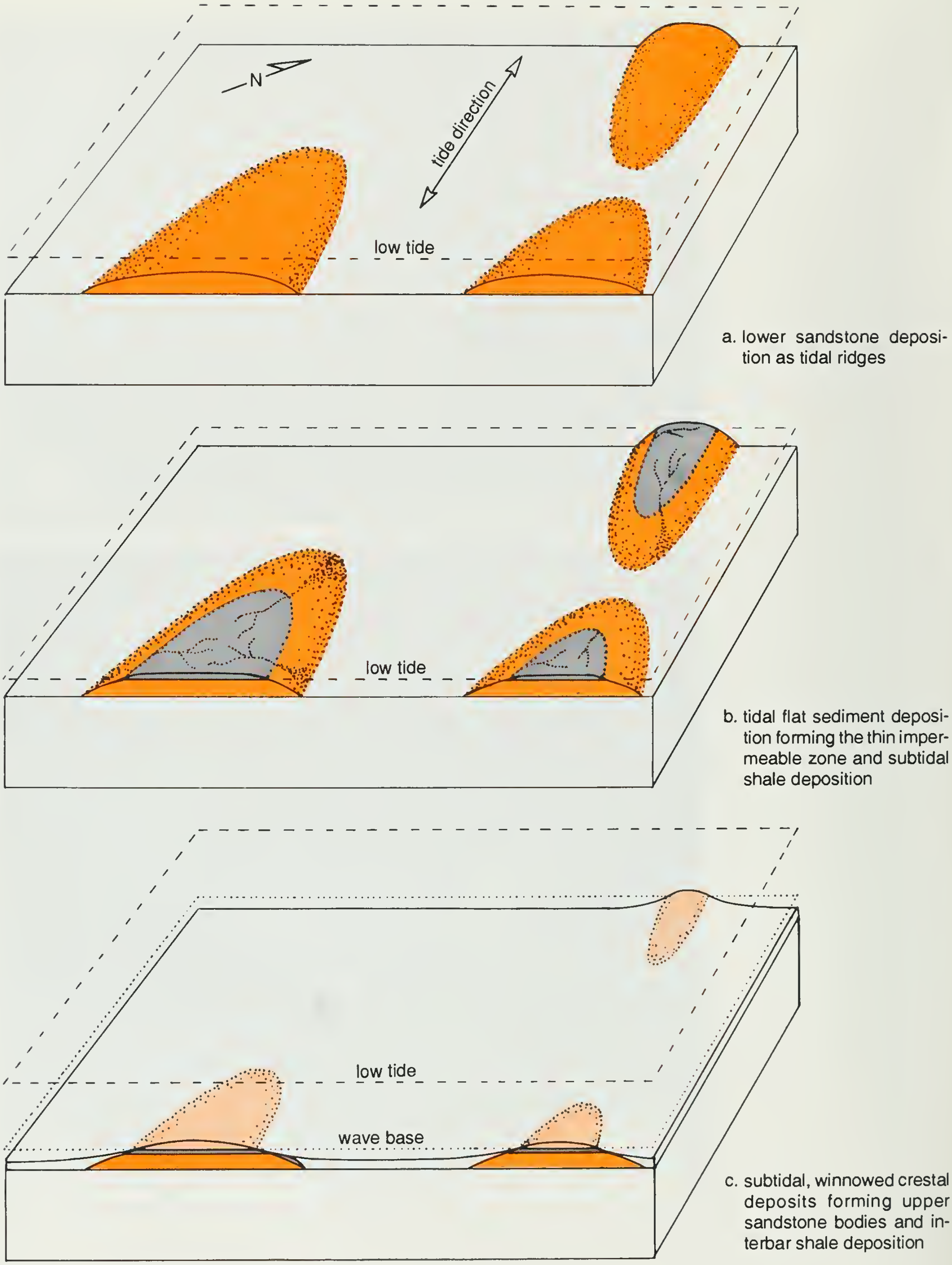


Figure 11 Block diagrams illustrating depositional environments at Energy Field. North arrow indicates present orientation.

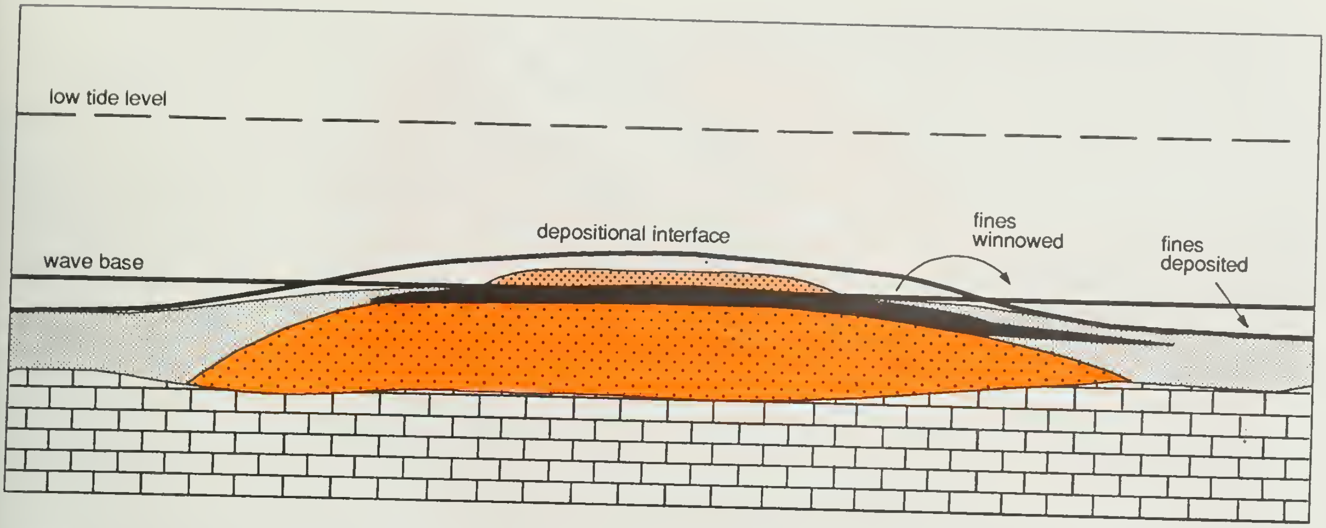


Figure 12 Subtidal winnowing of sediments by wave action concentrates coarser material on top of lower bars and produces upper sand reservoirs as crestal deposits.

Interfingering shale is interpreted as a contemporaneous marine deposit that included winnowed fines from the proto-upper sandstone sediments.

Evidence for this interpretation includes

- repeated areal association of upper and lower sandstones (figs. 6 and 8);
- ubiquitous occurrence of thick upper sandstones over tidal flat sediments (thin impermeable zone) deposited on previously high areas (figs 6 and 7);
- core containing the trace fossils *Conostichus* sp. and *Asterosoma* sp. of the *Cruziana* ichnofacies (plate 6, and appendix E) indicative of a shallow marine subtidal environment (Seilacher 1978, Chamberlain 1978) and increasing water depth;
- smaller grain size and very high clay content (now primarily recrystallized as cement) of this sandstone, as compared with the lower sandstone (plates 2–5, and 11)—features indicative of a lower energy environment.

The very thin but relatively coarser biocalcarenitc sandstone at the base of this unit (plates 1 and 6, and appendix E) probably records the transition in depositional environments from intertidal to subtidal deposition.

IDENTIFICATION AND CLASSIFICATION OF PLAY

Energy Field is a stratigraphic trap in which depositional environments controlled reservoir development and geometries. According to the nomenclature proposed by Rittenhouse (1972) for stratigraphic traps, the lower sandstone bar is classified as a current-transported, shallow marine tidal bar. The upper sandstone bar is classified as a current-transported, shallow marine, shallow-winnowed-crestal bar.

The two major bar complexes (north and south) are separated by an area that is almost 3/4 mile wide and lacks sandstone. In a study of present tidal ridge geometry, Off (1963) predicted this relationship for tidal ridges of the thickness of the lower sandstone bodies (24 feet). The areal association of the upper and lower sands and their similar dimensions and morphologies illustrate a predictable interval of tidal bar deposition which, if a bar crest trend and wave length were established, could be a useful indicator for exploration (fig. 13).

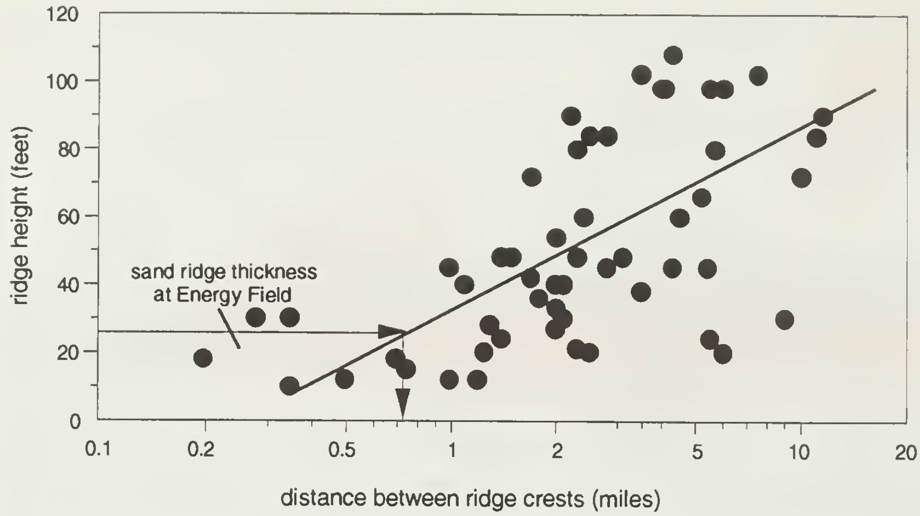


Figure 13 Relationship between rhythmic tidal ridge thickness and distance between ridges. (Modified from Off 1963; reprinted by permission.)

DEVELOPMENT AND PRODUCTION STRATEGIES

Several development and reentry locations in the south bar complex could be drilled, if economic conditions were favorable. Current spacing is probably adequate for drainage as the four separate reservoirs are horizontally continuous. Their lateral communication is inferred from the fact that original pressure in the south part of the field in 1969 was 985 psig, and wells drilled during the third stage of field development in 1988 encountered pressures on the order of 350 pounds—evidence of pressure bleed-off. A drill stem test in the north bar complex in 1991 had a final shut-in pressure of 927 pounds, demonstrating the lack of communication between the north and south complexes. Separate oil–water contacts of –1,974 and –1,923 feet (subsea) in the north and south bar complexes, respectively, confirm that the bar complexes are isolated from one another.

Successful implementation of waterflood programs in the unflooded reservoirs of Energy Field is highly probable, as indicated by the performance of the Energy Field Unit flood to the east (fig. 14). Waterflooding of the unit could have recovered more oil, if other injection wells had been drilled on the western perimeter of the lease, because the sweep would have been directed towards the thicker oil columns in the center of the southeast quarter of Section 4, T9S, R2E. It is probable that the reservoir underlying the west half of the southeast quarter of Section 4, T9S, R2E, is largely unaffected by waterflooding because of the areal sweep inefficiencies due to the current injection well geometry.

The original waterflood in Energy Field was engineered without complete understanding of the field geometry, particularly the undulating surface that defines the top of the sand (fig 14). The depression, which dips below the oil–water contact in the southern bar complex, separates the lower sandstone reservoir into two distinct, oil-productive compartments. These two reservoirs could be separately and efficiently drained with either a peripheral or patterned flood. A peripheral flood would yield the maximum oil recovery with a minimum of produced water; but because of the limited number of injection wells, the total oil-producing capacity would be lower than that of a patterned flood (Interstate Oil Compact Commission 1974). The impermeable seal between the upper and lower sandstone would necessitate separate development of the upper and lower sandstones.

Figure 14 Structure contour map on top of Aux Vases Sandstone, southern bar complex, Section 4, T9S, R2E. Cross section B–B′ shows Aux Vases sandstone interval. Solid contours show upper sand elevation; dashed contours show lower sand elevation.

An actual secondary recovery efficiency of 13.6%, as calculated in this report, might be improved with a better injection well geometry that leads to a more effective sweep of the reservoir. The nonflooded holdings in the south bar complex could yield an estimated 106,000 barrels of secondary oil.

CONCLUSIONS

The Aux Vases Formation at Energy Field consists of a complex, interfingering succession of sandstones and shales. Reservoir sandstones have developed in four separate bars, a lower and upper body in the northern portion of the field and a second set in the south. The lower bars are interpreted to be tidal ridge sands

deposited during a marine regressional event, and the upper bars to be winnowed crestal deposits formed on topographic highs over the tops of the lower ridges during marine transgression.

A zone of impermeable strata, interpreted as tidal flat sediments, vertically separates the upper and lower sandstones in both the north and south parts of the field. The sandstone bodies grade laterally and/or vertically into impermeable strata, and thereby create four separate sandstone reservoirs. Mapping on top of the sandstones shows a complex; undulous surface that dips below and rises above the oil–water contact. The field geometry is further complicated by the differing areal extents and lateral changes in thickness of the upper and lower sandstones.

The STOOIP at Energy Field is calculated to be 4,004,000 BO. Cumulative recovery through January 1992 was 306,000 BO. The recovery efficiency of at least 20.9% calculated for the Aux Vases reservoir leaves an estimated 531,000 BO of oil to be recovered. Waterflooding in newly discovered areas will account for the majority of this recovery. The addition of more injection wells in the previously flooded areas may increase overall recovery.

ACKNOWLEDGMENTS

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APPENDIX A RESERVOIR SUMMARY

Field Energy Field

Location Williamson County, Illinois

Tectonic/Regional Paleosetting Illinois Basin

Geologic Structure ramp

Trap Type stratigraphic

Reservoir Drive solution gas
Original reservoir pressure
southern bars 985 lbs
northern bars 927 lbs

Reservoir Rocks
Age Upper Valmeyeran of the Mississippian System
Stratigraphic unit Aux Vases Formation
Lithology sandstone
Depositional environment offshore tidal bar/ mixed siliciclastic carbonate
Productive facies tidal bar, shallow marine bar
Petrophysics (from core analyses)
ϕ *average* southern bars: upper bar 18.8%, lower bar 20.7%; northern bars: upper bar 20.1%, northern lower bar 21.1%
k liquid southern bars 150 md; northern upper bar— horizontal 19 md, vertical 13 md; northern lower bar—horizontal 78 md, vertical 45 md
S_w southern bars—upper bar 0.52, lower bar 0.51; northern bars—upper bar 0.42, lower bar 0.49
S_{or} 14.6%
S_{gr} N/A
Cementation factor N/A

Source Rocks
Lithology and stratigraphic unit New Albany (Devonian) Shales
Time of hydrocarbon maturation NA
Time of trap formation Late Valmeyeran

Reservoir Dimensions
Depth (absolute and subsea)
southern bars 2,370 (–1,913) ft
northern bars 2,390 (–1,958) ft
Areal dimensions 220 acres
Productive area 5,525 acre feet
Number of pay zones 1 with 4 reservoirs
Initial fluid contacts
southern bars oil/water –1,923 ft (subsea)
northern bars oil/water –1,974 ft (subsea)
Average sand (net and gross) thickness 25 ft
Initial reservoir temperature 84°F

Wells
Spacing 10 acre
Pattern regular

Appendix A *continued*

Reservoir Fluid Properties

Hydrocarbons

API gravity 39.4° @ 60°F
Oil viscosity 3.9 centipoise @ 84°F
Bubble-point pressure N/A
Formation volume factor 1.10

Formation water

Resistivity .063 ohm/meters @ 77°F
Converted to 84° using RT2 = RT1[(T1 + 6.77)/(T2 + 6.77)]
(Schlumberger, 1988 p. 5) = .058 ohm/meters
Total dissolved solids 127,526 mg/L
pH 6.76 @ 77°F
Eh –152 @ 77°F

Volumetrics

Original oil in place 4.4 million barrels of oil (MMBO)
Stock tank original oil in place 4.004 MMBO
Cumulative production .306 MMBO
Ultimate recovery
primary .292 MMBO
secondary .545 MMBO
Tertiary N/A
Recovery efficiency factor
primary 7.3%
secondary 13.6%

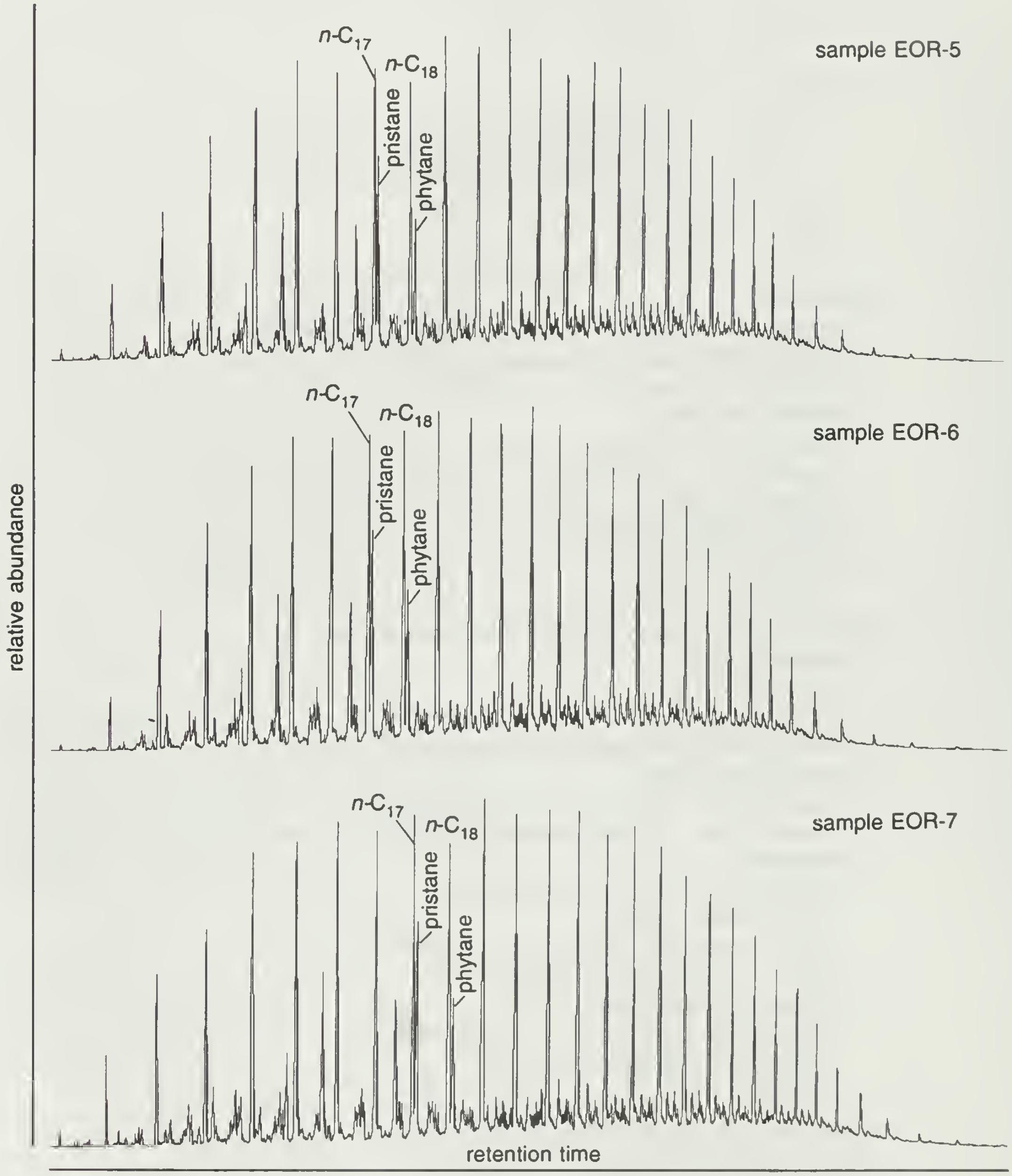
Typical Drilling/Completion/Production Practices

Completions
open hole 2
cased 20
Drilling fluid bentonite freshwater-based mud
Fracture treatment
open holes 20 quarts of nitroglycerine
cased holes gel salt water/sand fracture treatment in varying amounts
Acidization
1968–1988 250 gallons 15% MCA
1988–1990 none
1991 to present 250 gallons 7.5% MCA
Other 1 well lease oil fractured
Producing mechanism
Primary solution gas depletion. pump
Secondary waterflood, pump
Tertiary N/A

Typical Well Production (to date)

Cumulative production 15,000 BBL
Water to oil ratio N/A

APPENDIX B GAS CHROMATOGRAMS OF SATURATED HYDROCARBONS



APPENDIX C RESERVOIR FLUID ANALYSES

API number 1219923457
Operator Budmark Oil Company, Inc.
Well name Airport Morgan Coal No. 2
Location SW SW NW, Section 4, T9S, R2E
County Williamson
Field name Energy
Producing formation Aux Vases
Perforation depth (ft) 2,400–2,408
Surface elevation (ft) 483
Waterflooded No

Brine Analysis

Brine sample number EOR-B6
Temperature (°C) 17.2
Resistivity 0.0623 ohm meters @ 25°C
Eh (mV) –127.7
pH 7.09
Comment High gas, no corrosion inhibitor

Anion chemistry (in mg/L)

Br	190	I	9.7
Cl	79000	NH_4	36
CO_3	.04	NO_3	0.29
HCO_3	85	SO_4	2.1

Cation chemistry (in mg/L)

Al	0.1	Cr	<0.07	Na	43350	Sr	574
As	<0.5	Cu	<0.05	Ni	<0.15	Ti	0.04
B	4.02	Fe	2.8	Pb	<0.4	Tl	NA
Ba	17.4	K	181	Rb	NA	V	<0.08
Be	<0.003	Li	13.6	Sb	0.9	Zn	0.02
Ca	5300	Mg	2580	Sc	NA	Zr	0.03
Cd	<0.05	Mn	0.71	Se	<0.8		
Co	<0.07	Mo	<0.08	Si	3.8		

Oil Analysis

Oil sample number EOR-07

SARA analysis

saturates	72.26%
aromatics	20.10%
resins	6.80%
asphaltenes	0.85%

Paraffin analysis

% normal	47.19
% monocycle	6.62
% dicycle	2.47
maximum carbon	19

Selected hydrocarbon ratios

C_{17}/C_{18}	1.106
pristane/phytane	1.000
C_{17}/pristane	2.431
C_{18}/phytane	2.197

Other analyses

carbon preference index	0.976
carbon number extent	9–38
% napthalene	2.22

APPENDIX C *continued*

API number 1219923455
Operator Budmark Oil Company, Inc.
Well name Airport Morgan Coal No. 1
Location NW SW NW, Section 4, T9S, R2E
County Williamson
Field name Energy
Producing formation Aux Vases
Perforation depth (ft) 2,371–2,376
Surface elevation (ft) 463
Waterflooded No

Brine Analysis

Brine sample number EOR-B5
Temperature (^oC) 17.0
Resistivity 0.0633 ohm meters @ 25^oC
Eh (mV) –202
pH 7.12
Comment High gas, no corrosion inhibitor

Anion chemistry (in mg/L)

Br	NA	I	NA
Cl	74045	NH_4	24
CO_3	NA	NO_3	NA
HCO_3	NA	SO_4	NA

Cation chemistry (in mg/L)

Al	NA	Cr	NA	Na	42900	Sr	631
As	NA	Cu	0.19	Ni	<0.15	Ti	NA
B	4.06	Fe	10.4	Pb	<0.4	Tl	NA
Ba	5.59	K	174	Rb	NA	V	NA
Be	NA	Li	NA	Sb	NA	Zn	0.04
Ca	4510	Mg	2360	Sc	NA	Zr	0.1
Cd	<0.05	Mn	0.92	Se	NA		
Co	<0.07	Mo	<0.08	Si	2.17		

Oil Analysis

Oil sample number EOR-O6

SARA analysis

saturates	64.15%
aromatics	20.19%
resins	12.95%
asphaltenes	2.72%

Paraffin analysis

% normal	41.15
% monocycle	9.26
% dicycle	2.81
maximum carbon	22

Selected hydrocarbon ratios

C_{17}/C_{18}	0.987
pristane/phytane	1.330
C_{17}/pristane	1.539
C_{18}/phytane	2.072

Other analyses

carbon preference index	0.970
carbon number extent	10–39
% napthalene	3.19

Comment This is a Devonian oil.

APPENDIX C *continued*

API number 1219923456
Operator Budmark Oil Company, Inc.
Well name Morgan Coal No. 1
Location SE SW NW, Section 4, T9S, R2E
County Williamson
Field name Energy
Producing formation Aux Vases
Perforation depth (ft) 2,400–2,408
Surface elevation (ft) 480

Waterflooded No

Brine Analysis

Brine sample number EOR-B4
Temperature (°C) 18.3
Resistivity 0.0633 ohm meters @ 25° C
Eh(mV) –205
pH 7.02
Comment High gas, no corrosion inhibitor

Anion chemistry (in mg/L)

Br	NA	I	NA
Cl	73076	NH_4	26
CO_3	NA	NO_3	NA
HCO_3	NA	SO_4	NA

Cation chemistry (in mg/L)

Al	NA	Cr	NA	Na	42370	Sr	559
As	NA	Cu	0.19	Ni	<0.15	Ti	NA
B	3.79	Fe	5.7	Pb	<0.4	Tl	NA
Ba	6.63	K	173	Rb	NA	V	NA
Be	NA	Li	NA	Sb	NA	Zn	<0.02
Ca	4630	Mg	2200	Sc	NA	Zr	0.1
Cd	<0.05	Mn	0.68	Se	NA		
Co	<0.07	Mo	<0.08	Si	2.47		

Oil Analysis

Oil sample number EOR-05

SARA analysis		***Paraffin analysis***	
saturates	68.82%	% normal	38.83
aromatics	21.39%	% monocycle	7.41
resins	8.79%	% dicycle	3.31
asphaltenes	1.00%	maximum carbon	21

Selected hydrocarbon ratios		***Other analyses***	
C_{17}/C_{18}	1.065	carbon preference index	0.974
pristane/phytane	1.556	carbon number extent	10–38
C_{17}/pristane	1.450	% napthalene	5.45
C_{18}/phytane	2.120		

Comment This is a Devonian oil.

API number 1219923466
Operator Budmark Oil Company, Inc.
Well name Morgan Coal No. 3
Location NE SW NW, Section 4, T9S, R2E
County Williamson
Field name Energy
Producing formation Aux Vases
Perforation depth (ft) 2,389–2,394
Surface elevation (ft) 460
Waterflooded No

Brine Analysis

Brine sample number EOR-B7
Temperature (^{o}C) 17.2
Resistivity 0.0639 ohm meters @ 25^{o} C
Eh –146
pH 7.26

Comment

Anion chemistry (in mg/L)

Br	NA	I	NA
Cl	73716	NH_4	21
CO_3	NA	NO_3	NA
HCO_3	NA	SO_4	NA

Cation chemistry (in mg/L)

Al	NA	Cr	NA	Na	42720	Sr	614
As	NA	Cu	0.19	Ni	<0.15	Ti	NA
B	4	Fe	21.8	Pb	<0.4	Tl	NA
Ba	4.63	K	180	Rb	NA	V	NA
Be	NA	Li	NA	Sb	NA	Zn	<0.02
Ca	4700	Mg	2290	Sc	NA	Zr	0.1
Cd	0.02	Mn	1.02	Se	NA		
Co	<0.07	Mo	<0.08	Si	1.02		

API number 1219923477
Operator A. B. Vaughn Oil Properties
Well name Eovaldi–Fairchild No. 3
Location NW NW SE, Section 4, T9S, R2E
County Williamson
Field name Energy
Producing formation Aux Vases
Perforation depth (ft) 2,364–2,370
Surface elevation (ft) 442
Waterflooded no

Brine Analysis

Brine sample number EOR-B60
Temperature (^oC) 15.5
Resistivity @ 25^o C 0.0632 ohm meters
Eh (mV) –102
pH 6.63
Comment Sample collected at 1:10 pm; 2% oil

Anion chemistry (in mg/L)

Br	180	I	10
Cl	79000	NH_4	31
CO_3	0.01	NO_3	0.25
HCO_3	60	SO_4	1.8

Cation chemistry (in mg/L)

Al	NA	Cr	NA	Na	44210	Sr	441
As	NA	Cu	NA	Ni	NA	Ti	0.04
B	1.8	Fe	6	Pb	NA	Tl	NA
Ba	12.5	K	190	Rb	NA	V	NA
Be	NA	Li	12	Sb	NA	Zn	NA
Ca	5370	Mg	2510	Sc	NA	Zr	NA
Cd	NA	Mn	0.74	Se	7.8		
Co	NA	Mo	NA	Si	3.3		

APPENDIX D MINERAL COMPONENTS FROM X-RAY DIFFRACTION ANALYSIS

API number	Depth ft	Clay index*	%I	%I/S	%C	%Q	%Kf	%Pf	%CC	%D
19923465	2387.6	.05	1.6	0.9	2.4	81	0.0	8.2	6.0	0.0
19923465	2388.4	.04	1.2	1.1	1.9	57	0.2	8.2	31.0	0.0
19923465	2390.1	.05	1.4	0.7	2.5	85	0.6	2.6	6.7	0.0
19923465	2392.7	.03	0.8	0.3	1.7	73	0.2	7.8	17.0	0.0
19923465	2394.7	.04	1.0	0.5	3.0	76	0.4	6.3	13.0	0.0
19923465	2395.2	.07	1.6	0.9	4.1	63	0.0	2.5	27.0	0.0
19923491	2392.5	.10	1.9	6.5	1.5	71	1.4	3.3	13.9	0.4
19923491	2394.0	.10	2.6	4.1	3.4	73	1.0	3.4	12.2	0.1
19923491	2395.5	.11	4.4	6.4	0.7	67	0.8	1.8	16.5	2.3
19923491	2396.0	.38	12.8	24.6	1.0	55	1.7	3.0	0.9	1.3
19923491	2397.0	.24	7.2	15.0	1.4	69	1.4	5.2	0.5	0.0
19923491	2397.0	.13	4.4	7.6	0.9	61	1.2	4.1	12.2	8.2
19923491	2398.0	.03	0.7	1.8	0.7	87	1.3	3.8	5.1	0.0
19923491	2402.5	.04	0.9	2.2	1.2	87	0.0	2.6	6.2	0.0
19923491	2412.0	.04	0.6	2.6	1.2	88	0.7	3.9	2.9	0.0
19923491	2414.5	.09	1.4	5.3	2.6	82	0.4	3.2	5.4	0.0
19923491	2417.8	.09	1.3	5.0	2.7	84	0.3	3.3	4.0	0.0
19923491	2419.5	.20	2.6	12.0	5.2	75	0.3	2.5	2.7	0.0
19923491	2419.7	.04	0.4	1.3	1.9	90	0.9	3.0	2.1	0.0
19923491	2420.0	.09	1.6	4.3	2.9	82	0.7	2.5	5.6	0.0

Abbreviations: I, illite; I/S, mixed layer illite/smectite; C, chlorite; Q, quartz; Kf, potassium feldspar; Pf, plagioclase feldspar; CC, calcium carbonate; D dolomite.

*clay index = 4 × 020 clay peak (19920) ÷ adjusted sum nonclay peaks

All samples are of the Aux Vases Formation. Samples with an API number of 19923465 are from the Budmark Oil Company, Morgan Coal No. 2 well, Section 4, T9S, R2E. Samples with an API number of 19923491 are from the Budmark Oil Company, Burr Oak No. 3 well, Section 33, T8S, R2E.

APPENDIX E CORE DESCRIPTION OF THE BURR OAK NO. 3 WELL, BUDMARK OIL COMPANY NE SE NE, Section 33, T8S, R2E, Williamson County

Aux Vases Formation

Depth (ft)	
2,392.3–2,395.4	*Sandstone* — light greenish gray; very fine grained; subangular; slightly calcareous; well sorted; moderately well indurated; contains silica and calcite cement. Bedding is horizontal with some thin clay drapes on ripples; bioturbated, heavily in some areas, with a notable vertical burrow of *Conostichus* sp. and horizontal *Asterosoma* sp. at 2,393.5 feet (plate 6); some shale streaks 1/16 to 1/8 inch wide, 0.5 to 1 inch long, horizontal to slightly inclined, and rippled; horizontal streaks and patches of asphalt and oil saturation; porous, permeable; large (1/4 inch) fossil fragments near base. Thinly, algally laminated green sand and numerous fossil fragments make up the basal fraction. Sharp contact on an irregular surface occurs at base of unit.
2,395.4–2,396.1	*Silty sandstone* — very fine grained, subround, calcareous, light olive gray; contains a few olive gray shale laminae, each 1/16 to 1/8 inch thick, numerous algal laminations and algally bound intraclasts, and numerous coarse grained fossil fragments (crinoids, brachiopods bryozoans, unidentifiable pelmatazoans). A channel cut in the uppermost part of this interval is filled with coarse fossil fragments in a fine grained matrix (plate 2). Unit is bioturbated; at least four surfaces show penecontemporaneous erosion; bedding between surfaces is primarily massive, which is apparent from changes in size and content of fossil fragments; unit is neither porous nor permeable. Sharp contact occurs on an undulous surface at base of unit.
2,396.1–2,396.85	*Sandy siltstone grading to silty shale* — light olive gray with olive gray shale laminae and intraclasts grading to an olive gray shale with light olive gray lenses and laminae of silt and very fine sand. Shale is fissile; laminae are continuous at base of unit and parted in places, but still horizontal in the lower part and broken and disrupted at their highest occurrence (mud cracks?). The unit is noncalcareous except at fossil fragment locations. The rock is nonporous and impermeable. Contact at the base is sharp.
2,396.85–2,396.9	*Silty biocalcarenite* — gray brown with olive gray shale laminae; very poorly sorted, nonporous, impermeable. Coarse grained bioclasts of brachiopods, bryozoans, crinoids, and possibly molluscs are supported in a matrix of very fine grained silty sandstone with algal laminations and algally bound intraclasts. Sharp contact occurs at the base of the unit.

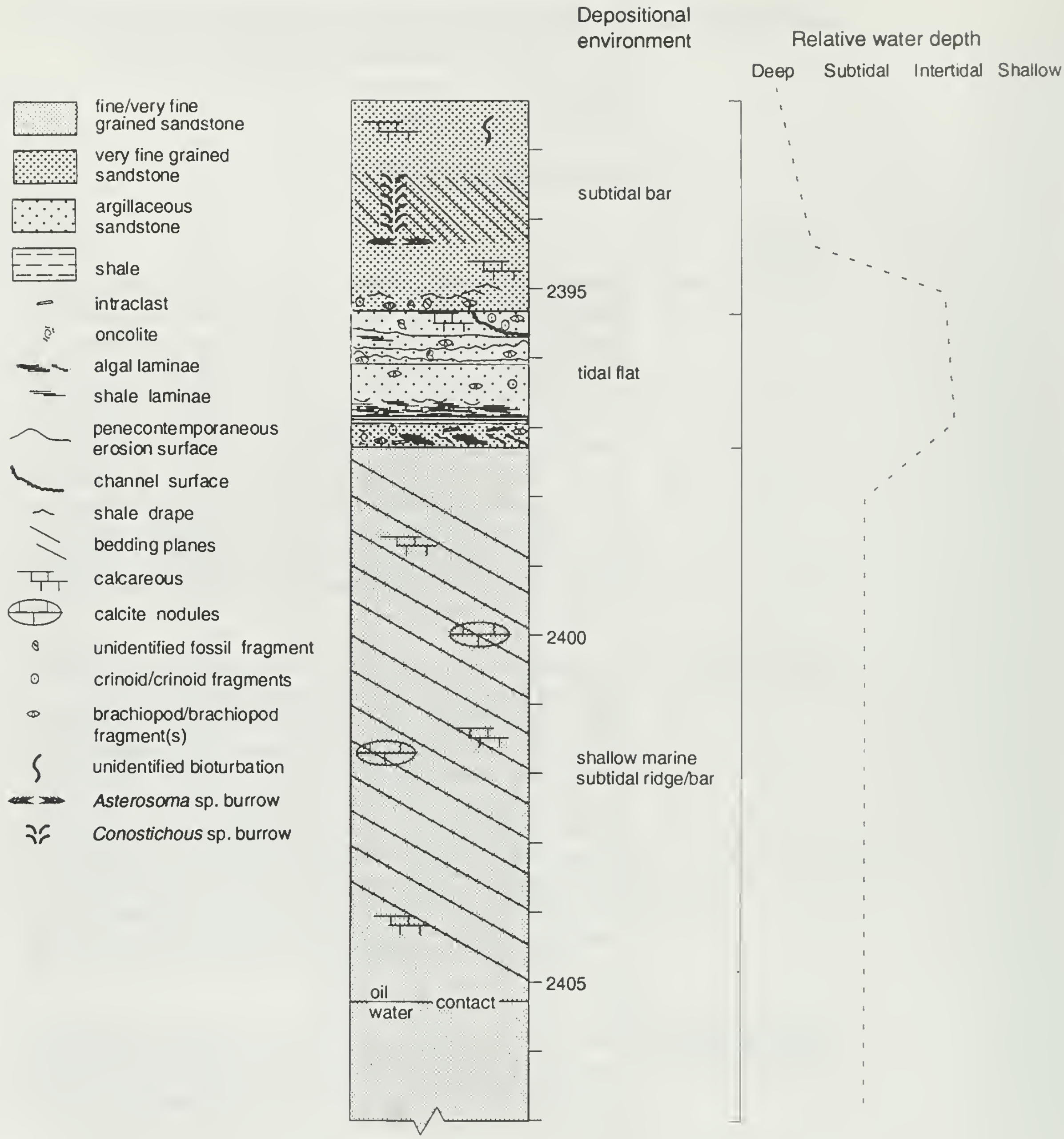


Figure E-1 Schematic core description of Budmark Oil Company, Burr Oak No. 3 well.

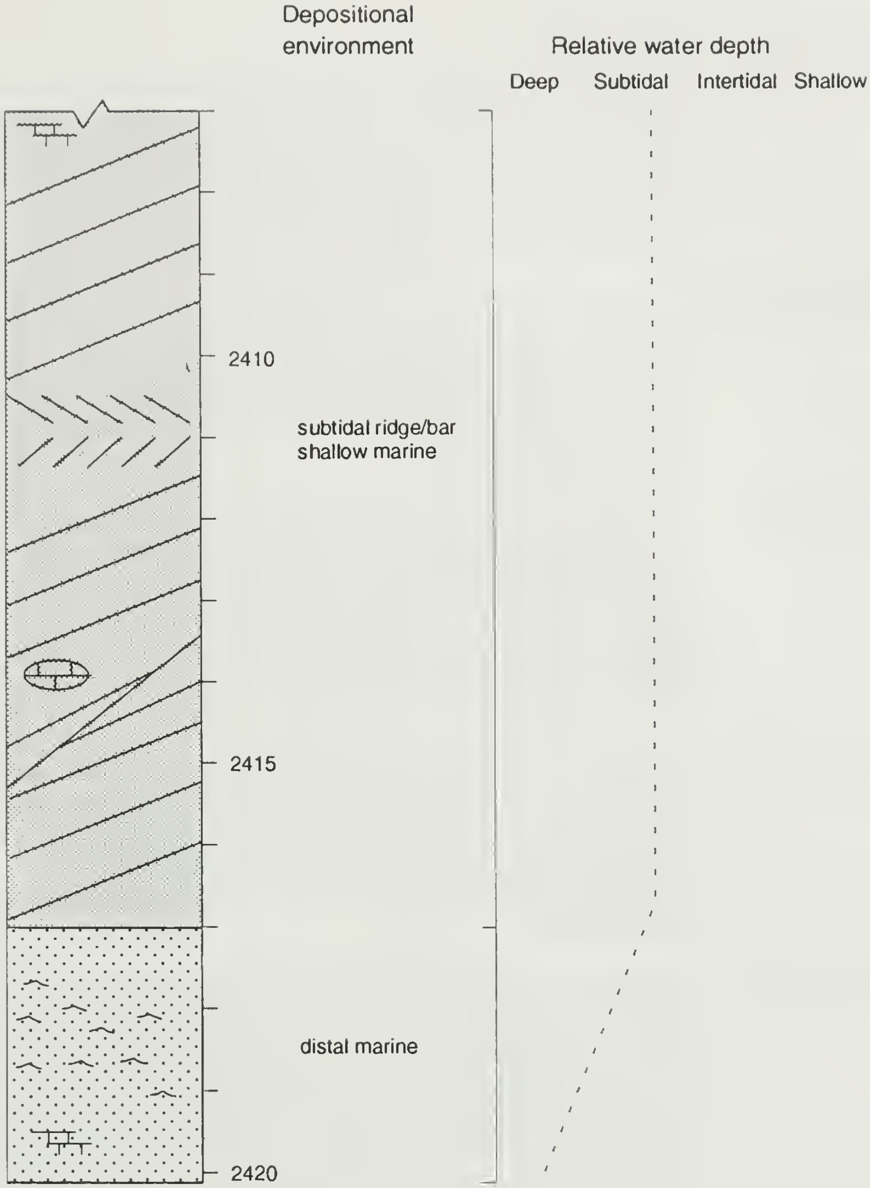


Figure E-1 *(continued)*

2,396.9–2,396.95	*Sandstone* — gray green, very fine grained, subround, well sorted, porous, permeable, noncalcareous; contains a few, discontinuous shale laminae. Unit is crossbedded with well defined reactivation surfaces; poorly developed gray brown clay drapes occur on bedding surfaces. Thickness is irregular. Sharp contact occurs on an irregular surface at the base.
2,396.95–2,397.3	*Sandstone* — gray green, very fine grained; algally bound sandstone intraclasts and oncolites predominate (plate 5); algal laminae are black and commonly pyritized. Unit is calcareous; contains common fossil fragments that are coarse grained; appears marginally porous and impermeable. Contact at base is sharp.
2,397.3–2,405.3	*Sandstone* — fine grained, dark yellowish brown where oil stained, yellowish gray where there is no staining; slightly calcareous, well indurated with silica cement; bimodally well sorted, porous, permeable; some blue green reduction spots; crossbedded. Rare calcite nodules are sometimes aligned along bedding. Oil–water contact occurs at 2,405.3 feet, as evidenced by change in color and salt precipitation.
2,405.3–2,417.0	Lithology and grain sizes similar to interval above, but asphalt staining has enhanced sedimentary structures, including bimodal rhythmite crossbedding (e.g. 2,014 feet, plate 3), reversed current bedding (e.g. 2,411 feet, plate 4), and reactivation surfaces (e.g. 2,014 feet, plate 3). Contact at base is sharp.
2,417.0–2,420.1	*Sandstone* — very fine grained, well sorted, light gray, subround, very slightly calcareous, well indurated with silica cement, horizontal and mottled to ripple bedded. Some flaser-like bedding and thin dark gray clay drapes occur on bedding surfaces. Matrix contains abundant silt and clay; the unit is porous, slightly permeable. Some asphalt staining occurs in lower part, which becomes more calcareous towards the base; the last inch is impermeable.

Illinois State Geological Survey
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Champaign, IL 61820-6964

Address Correction Requested